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Itek 78-9549A-2

Revision A

CR 151848

(NASA-CR-151848) FEASIBILITY STUDY FOR THE
APPLICATION OF THE LARGE FORMAT CAMERA AS A
PAYLOAD FOR THE ORBITER PROGRAM Final
Report (Itek Corp.) 195 p HC A09/MF A01

N79-10393

Unclas
CSCL 14E G3/35 36874

FINAL REPORT
SEPTEMBER 1978

FEASIBILITY STUDY FOR THE APPLICATION
OF THE LARGE FORMAT CAMERA
AS A PAYLOAD FOR THE ORBITER PROGRAM

Contract NAS9-15490

21 November 1977 through 14 July 1978

Prepared for:

NASA - LYNDON B. JOHNSON SPACE CENTER
SHUTTLE PAYLOAD PROCUREMENT SECTION
HOUSTON, TEXAS 77058



Itek

Optical Systems Division

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1. INTRODUCTION

The Large Format Camera (LFC) is designed as a 30-centimeter-focal-length cartographic camera system that employs forward motion compensation in order to achieve the full image resolution provided by its 80-degree field angle lens. This study was undertaken to assess the feasibility of application of the current LFC design to deployment in the Orbiter program as the Orbiter Camera Payload System (OCPS), and to define the changes that are necessary to meet such a requirement. The secondary goal of this assessment process has been to evaluate current design and any proposed design changes, relative to possible future deployment of the LFC on a free-flyer vehicle or in a WB-57F.

The additional goals of this study activity were to define the preliminary interface requirements for the LFC in terms of:

1. Structural and mechanical
2. Environmental
3. Power
4. Electrical
5. Functional
6. Installation
7. Ground support
8. Mission parameters.

2. PROGRAM SUMMARY

Study activity commenced by comparing the physical and functional features of the current LFC design with the desired features for the OCPS. The features to be added to the design were:

- | | |
|--|-----------------------------------|
| 1. Film load increased from
610 to 1,220 meters | 5. Exposure sensor |
| 2. End-of-operation marker | 6. Thermal door and shroud |
| 3. Film-change detector | 7. Extended command set |
| 4. Chromatic filter changer | 8. TM generation and conditioning |
| | 9. Self-test logic |

Having ascertained the extent of new features, the LFC design layouts were modified to incorporate these features. In this modification process, the evolving LFC envelope was evaluated relative to mounting compatibility in the ERNO pallet, in the standard test rack, on the MMS mounting ring, and in the WB-57F pallet.

During the establishment of the mechanical configuration, a separate activity defined both the internal and the external interconnections required for the OCPS.

At this juncture in the program, a meeting was convened at NASA-JSC to discuss interface ideas and options with JSC discipline experts in the areas of electrical, structural, thermal, and general functional interfaces.

After the completion of hardware-related interface definition, study activity turned to typical space mission interface definition. Investigations here centered around orbits with inclinations of 28.5, 57, and 70 degrees, and those compatible with sun-synchronous orbits at varying altitudes. The parameters evaluated were:

- The altitudes for each inclination where earth coverage at the equator will be optimized
- The sensitivity in altitude achievement as relates to "gap" generation in the equatorial coverage
- LFC exposure time requirements relative to solar altitude for various film/filter/processing combinations
- LFC film selection merit-order relative to dynamic resolutions where the variables are solar altitude and vehicle attitude rates
- Geographically-related illumination conditions to be expected during a mission for launch times varying both over the year and over the day
- Photographic coverage characteristics as related to geographical areas and film utilization

- Activity and power consumption timelines for typical missions

and, finally,

- Geographically-related climatological conditions to be expected during a mission for launch times varying over the year and over the day.

In the context of this program summary, we wish to extend our appreciation to the Technical Contract Monitor, Mr. B.H. Mollberg, for his timely support in technical liaison matters and in the provision of pertinent technical documentation.

3. DISCUSSION

3.1 LFC CONFIGURATION AND INTERFACE REQUIREMENTS

3.1.1 "Current Design Status"

At the start of this study activity the "current design status" of the LFC, a derivative of the Metritek-30 aircraft camera design, incorporated the following features:

- A 30.5-centimeter cartographic lens
- A rotary shutter
- Interchangeable chromatic filters attached to the front of the lens cell
- A pressurizable and insulated lens cell enclosure incorporating active heating blankets to ensure constant and consistent control of the refractive properties of the lens
- A pressure- and temperature-controlled film magazine providing for vacuum clamping of the film, cam-driven forward motion compensation, mission data annotation, and a film capacity of 630 meters
- An electronic control box capable of accepting overlap, V/h, exposure time and start/stop commands, and producing all camera control functions.

In order to bring the above-described configurations to a state consistent with general space application, the LFC design required numerous internal design changes; but only a few changes that would affect external interfaces. These changes were as follows:

- A protective thermal door and environmental enclosure was required to protect the lens cell assembly from excessive heat loss through the front of the lens and from heat gains produced by solar flux
- The film load was required to be larger; a target film load of 1,220 meters was established
- The functions of the camera control assembly were increased to provide more control options, TM output, and system self-test.

In the following paragraphs, we discuss the reconfiguration investigation and its outcome.

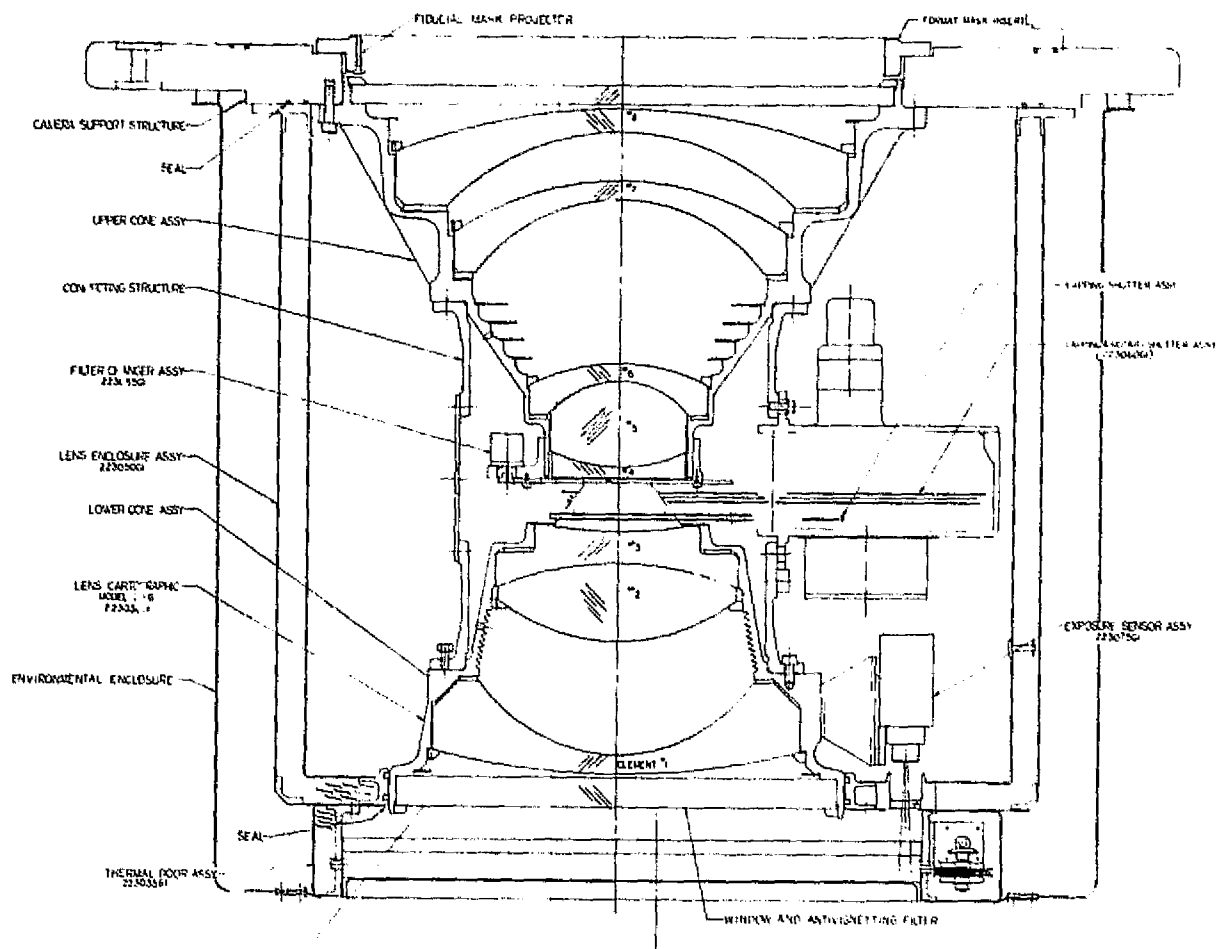


Figure 3-1 - LFC lens cell assembly

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3.1.2 Lens Cell Assembly Configuration

The only material envelope changes introduced into the lens cell assembly in order to meet added requirements were an increase in length occasioned by the addition of the thermal door assembly and an increase in lens barrel diameter caused by the addition of the surrounding environmental enclosure. Fig. 3-1 is a section of the lens cell assembly and Fig. 3-2 is an isometric sketch of the exterior shape of the environmental enclosure.

3.1.3 Film Magazine Assembly Configuration

3.1.3.1 Alternative Configurations

Having established the lens cell assembly envelope, it now became necessary to investigate alternative film magazine configurations and their impact on envelope size and functional characteristics. In all alternative designs, the magazine base assembly remained intact, since it included all of the mechanisms significant to the proper maintenance of image resolution. Consequently, the problem became one of how to best house the 1,220-meter film load.

Three configurations were evaluated. The first is illustrated in Fig. 3-3. This configuration featured a vertical arrangement of film spools having unequal flange diameters that allowed an overlapping of the larger diameters. Design merits and demerits are shown on the figure. The total length of the assembly ruled out this configuration as being unadaptable to WB-57F deployment.

The second configuration evaluated is illustrated in Fig. 3-4. This configuration is more conventional since the spools are horizontally arranged. Again, unequal spool flanges and overlapping were employed to reduce envelope size. This design is susceptible to height reduction for aircraft deployment through the use of standard 214-meter spools and a lower profile top cover.

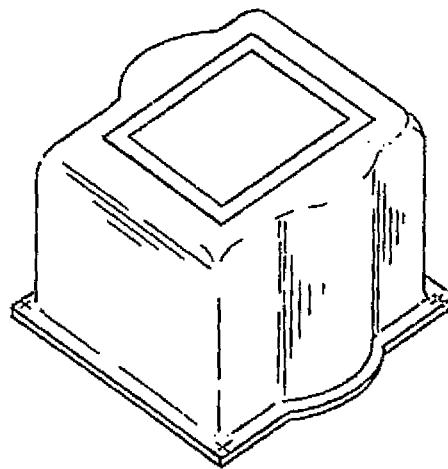
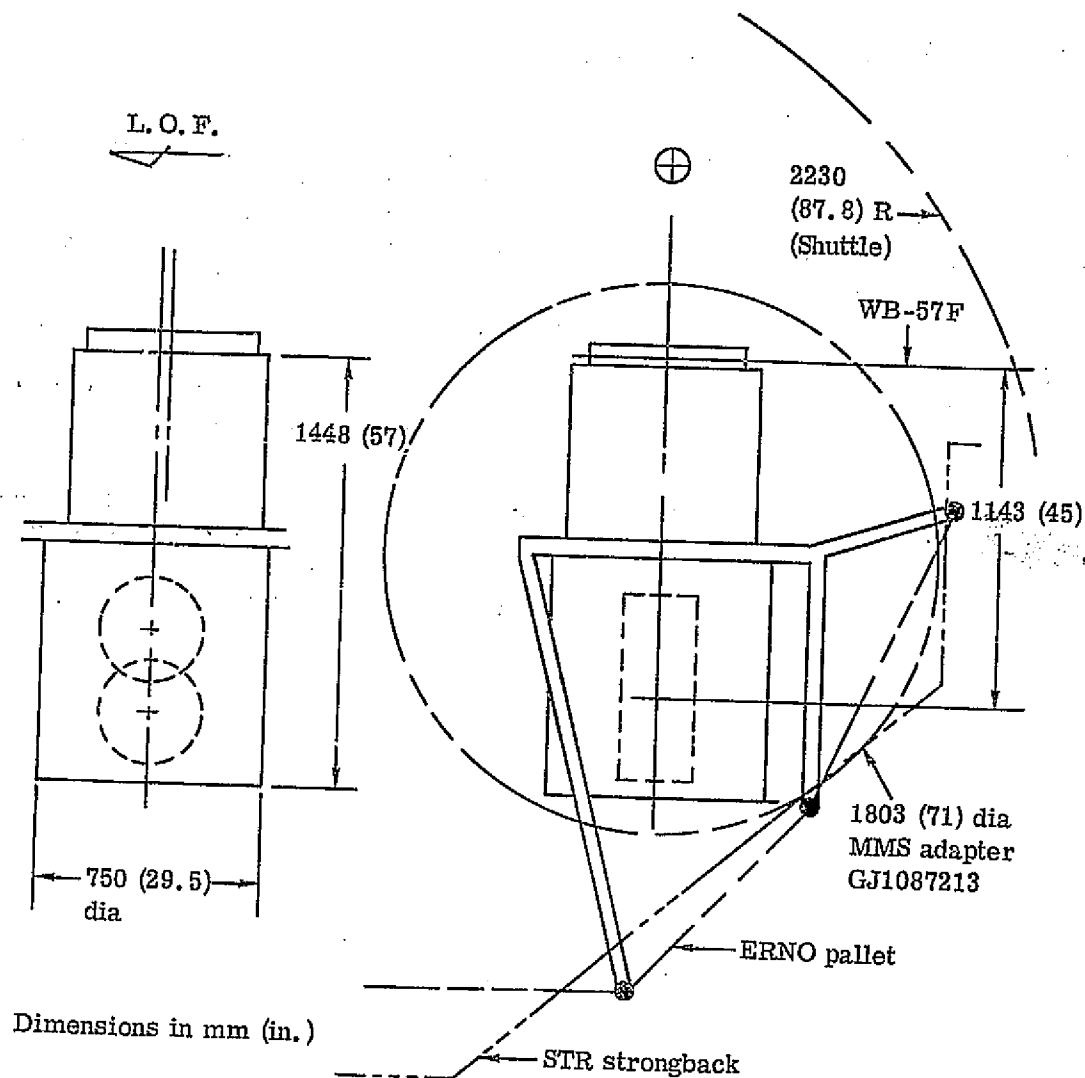


Figure 3-2 - Environmental enclosure



Merits

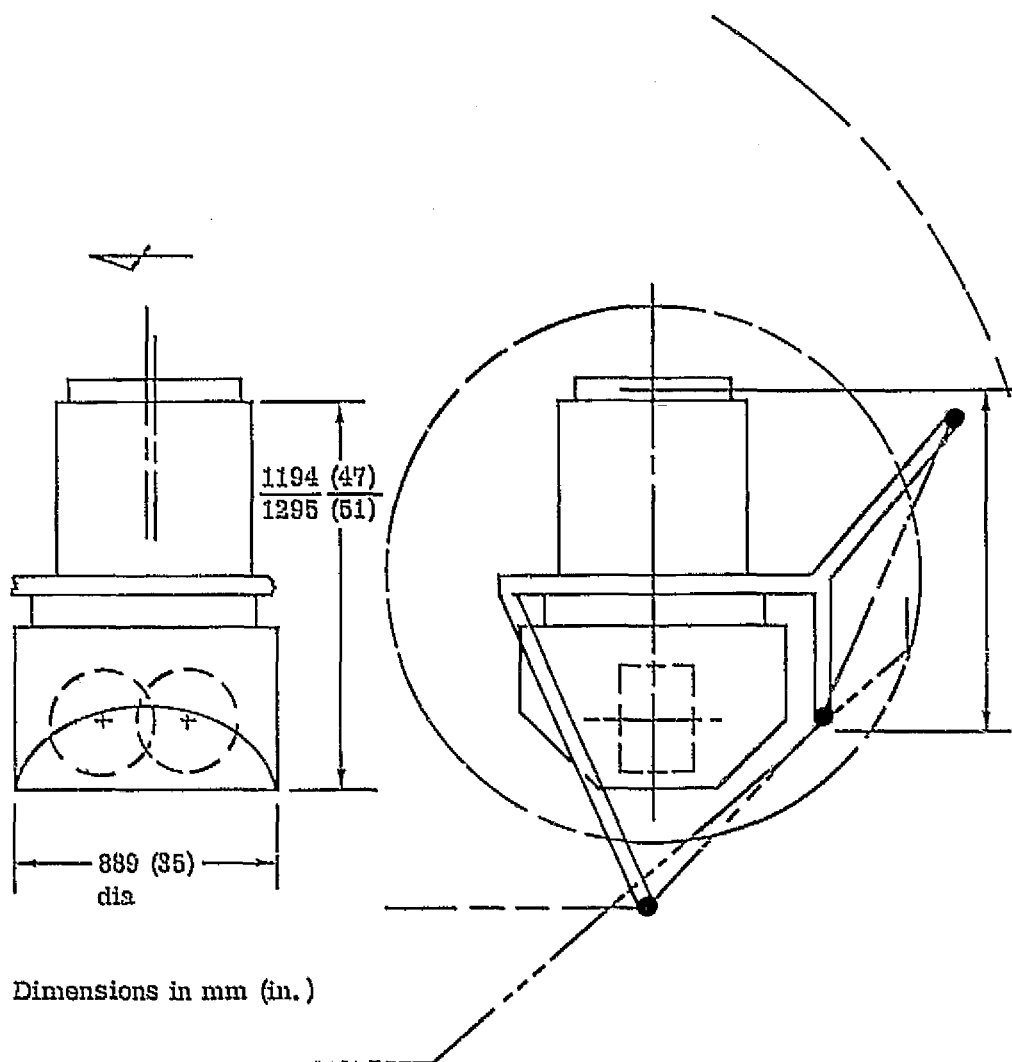
- Simple film path
- Simple thermal/pressure enclosure

Demerits

- Long total assembly
- Center of gravity shifts vertically
- Does not fit into WB-57F

Figure 3-3 -- Configuration A

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Dimensions in mm (in.)

Merits

- Minimum volume
- Modification to shorter length for aircraft use
- Minimum center of gravity shift

Demerits

- More difficult to thread than Configuration A

Figure 3-4 - Configuration B

The third configuration evaluated is illustrated in Fig. 3-5. Here the spools were brought outside the lens cell assembly to minimize the total assembly height. While this configuration would lend itself to WB-57F deployment, it suffers a large center of gravity shift during operation as film (about 32 kilograms) is transferred from one spool to the other. Additionally, pressurization sealing and thermalization would become increasingly difficult for this configuration.

On balance, the horizontally overlapped spool configuration (Fig. 3-4) was deemed the better overall choice and this configuration was more fully developed.

3.1.3.2 Final Configuration

The layout of final film magazine assembly configuration resulted in the sectional illustration shown in Fig. 3-6. The assembly as shown is about 88.5 centimeters long and 53.6 centimeters high. Employing smaller film spools and an alternative cover, the assembly height decreases to about 41.6 centimeters.

3.1.4 Camera Electronics Assembly

The LFC camera electronics assembly, in order to meet space deployment requirements, will comprise the functional components depicted in Fig. 3-7. This assembly is to be a separate cable-connected unit and, in the context of this study, the features of importance were the electrical interfaces and the physical envelope.

The external electrical interfaces investigated included power, command, flags and TM data.

The "best estimate" of the physical dimensions of the camera electronics assembly is shown in Fig. 3-8. Thermal and vibration isolation will be part of the package and the entire unit will fasten down through a mounting plate.

3.1.5 Pneumatics System

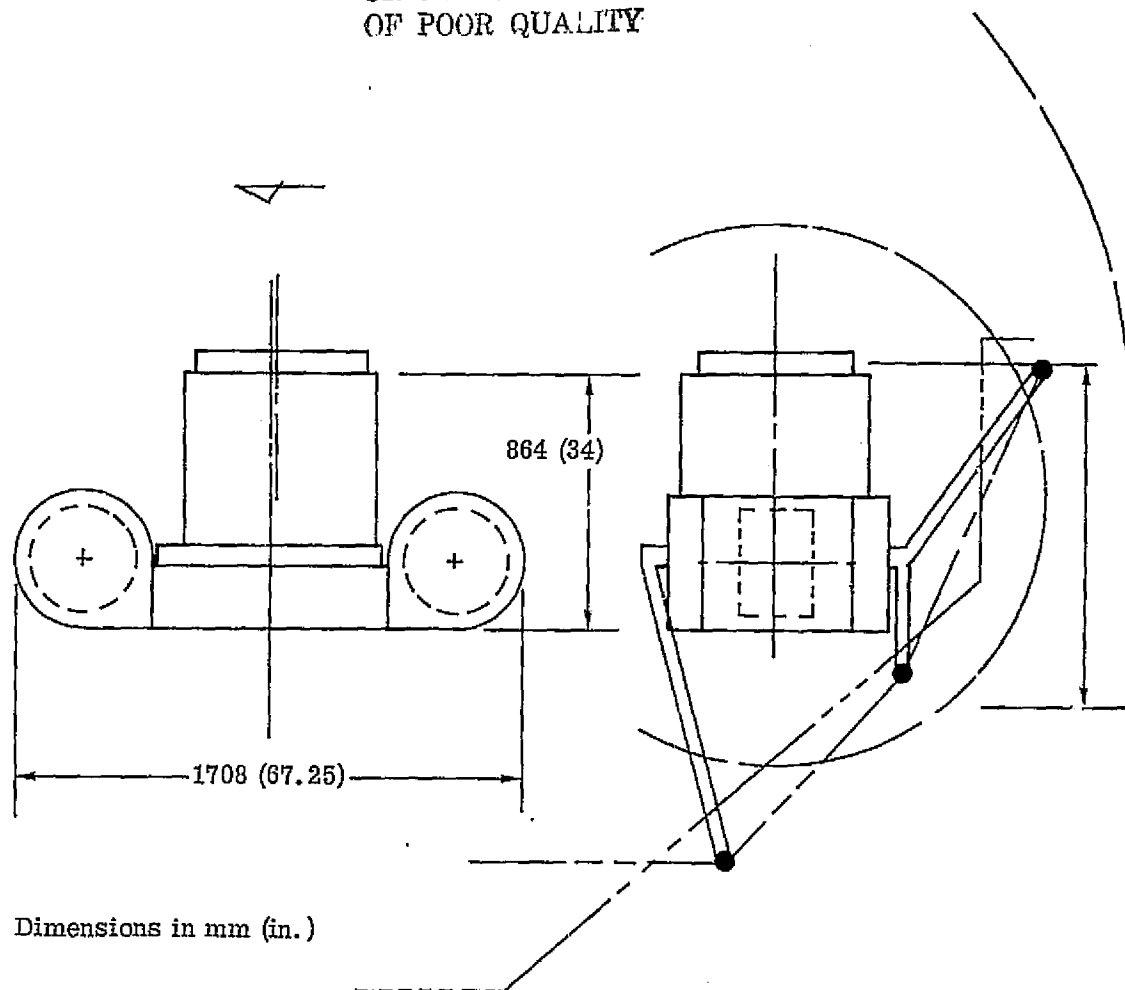
The LFC (lens and magazine) will be pressurized internally to about 1 psi above the operational ambient. This pressurization serves to allow the use of a vacuum film platen and to control the refractive properties of the lens. This latter property is particularly important relative to variable-altitude aircraft deployment of the LFC.

Fig. 3-9 depicts the character of the LFC gas system. The primary external interface in this system is that with the high pressure gas supply. The secondary interfaces are the over/under pressure vents, which have little external significance.

3.1.6 Assembly Interconnections

The interconnections within the LFC and the interface connections with the host vehicle are diagrammed in Fig. 3-10. Interface connections are electrical and gas; as are the interconnections between major assemblies.

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Dimensions in mm (in.)

Merits

- Shortest overall height
- Relatively easy to thread

Demerits

- Very long magazine
- Difficult to seal for pressurization and thermalization
- Large center of gravity shift

Figure 3-5 - Configuration C

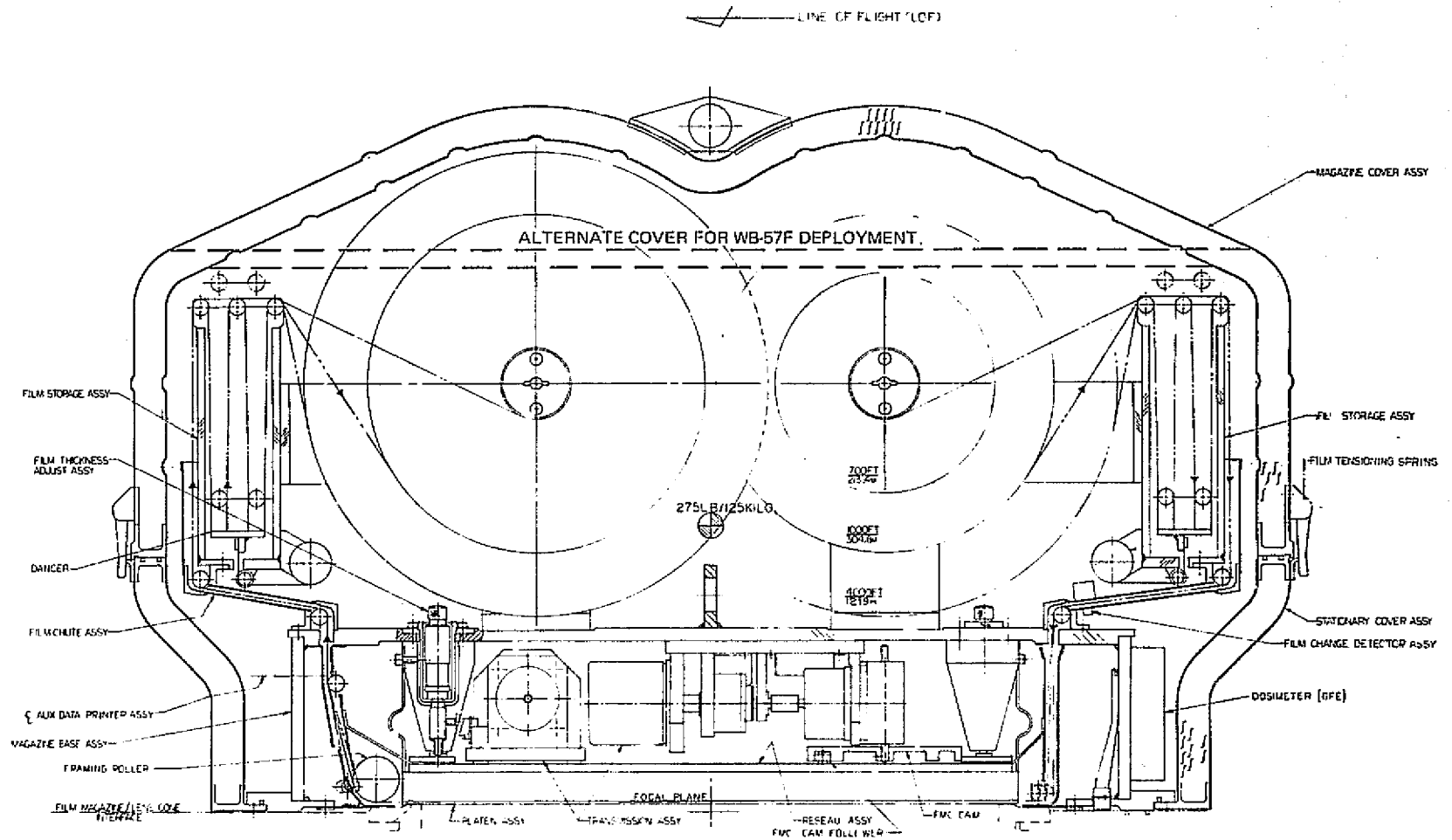


Figure 3-6 - Film magazine assembly

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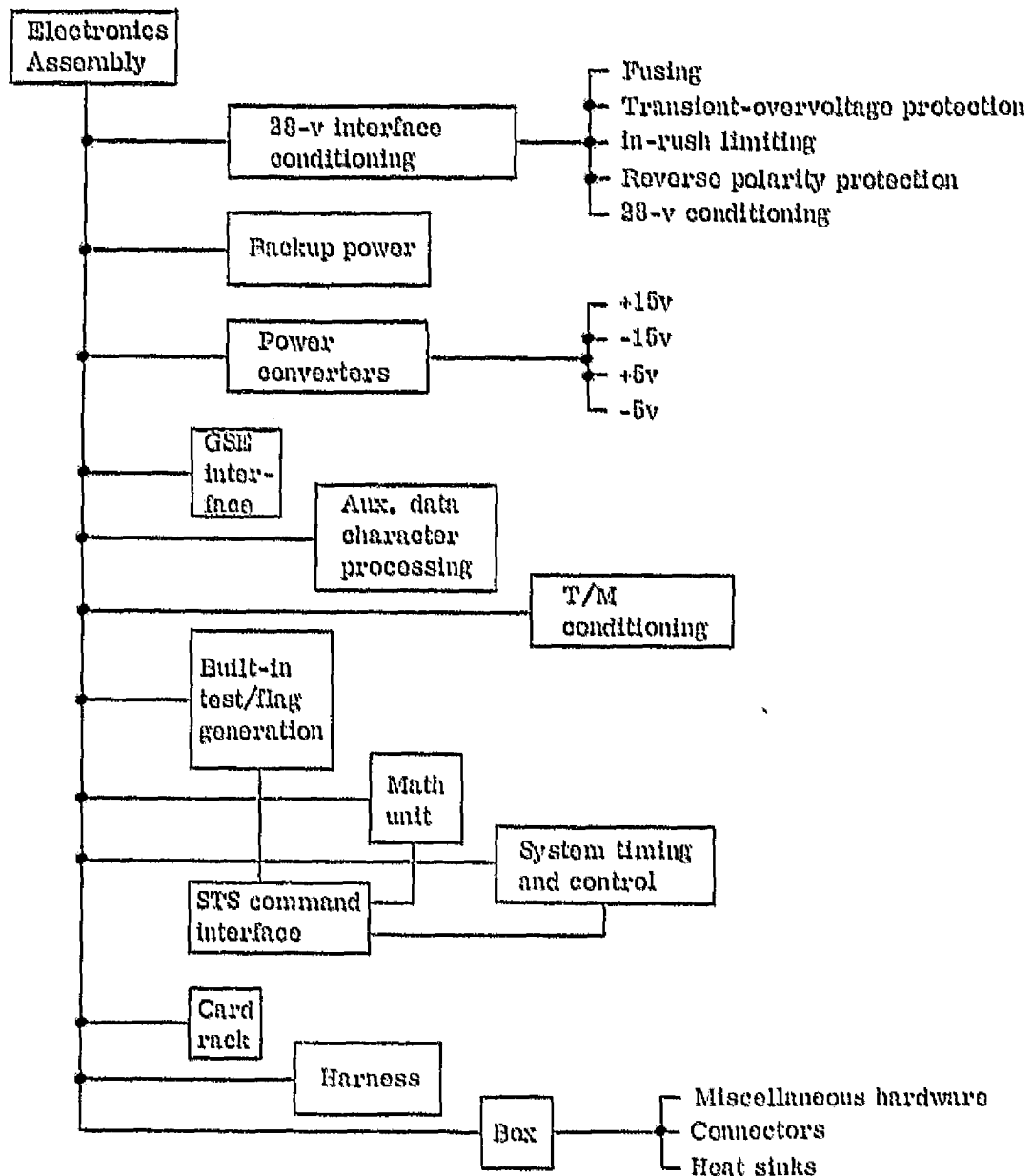


Figure 3-7 -- Electronics assembly functional tree

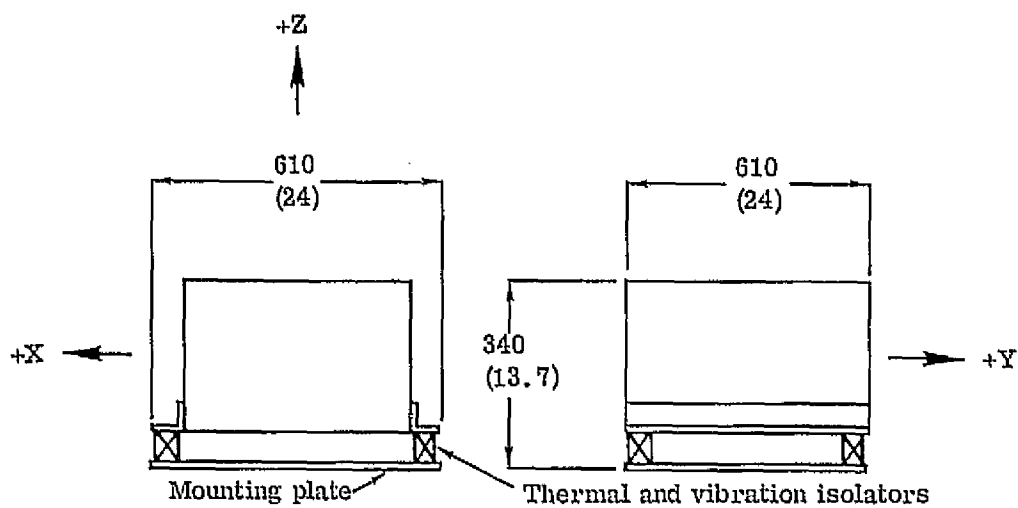


Figure 3-8 - Camera electronics envelope

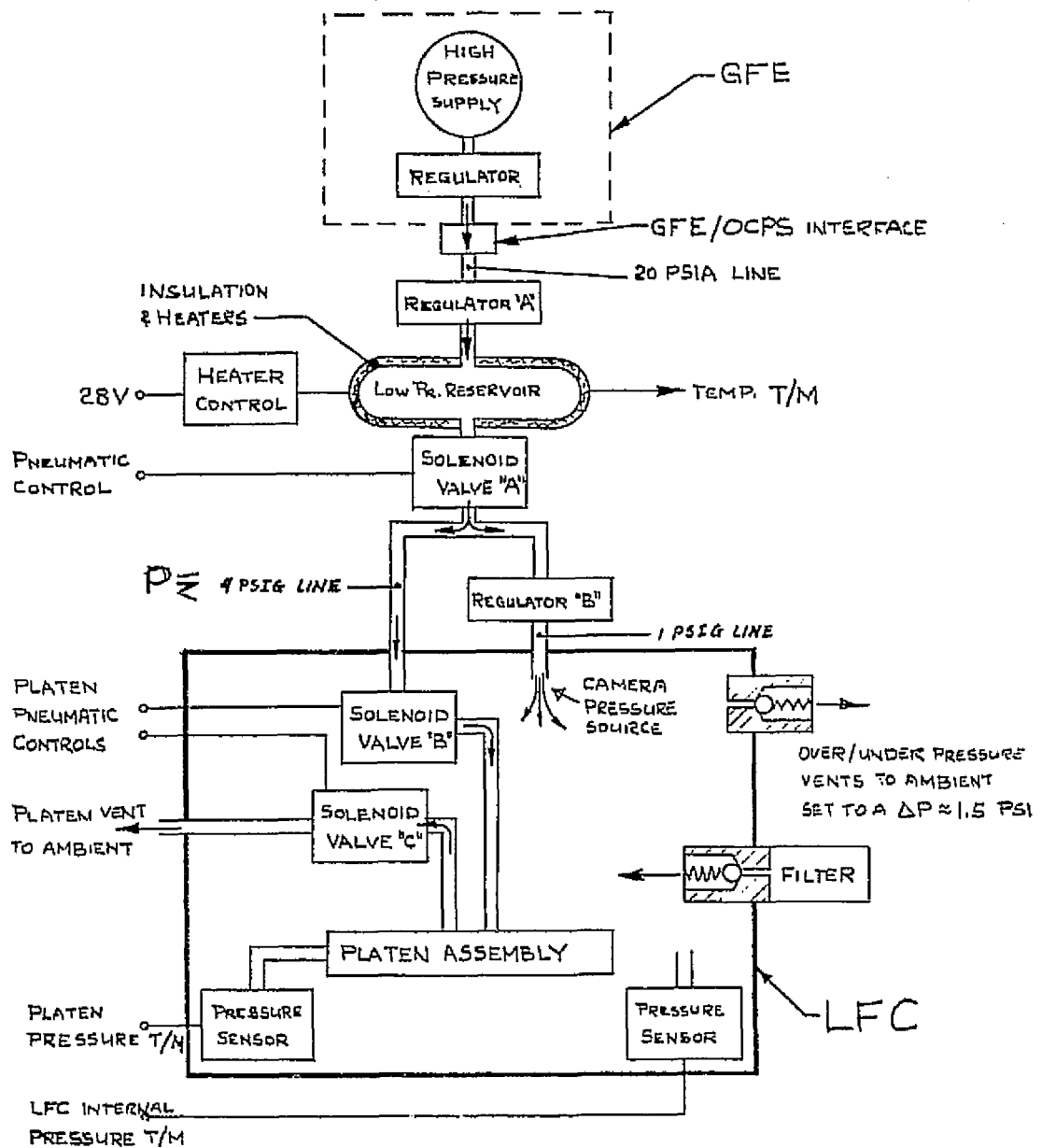


Figure 3-9 - LFC pneumatics system

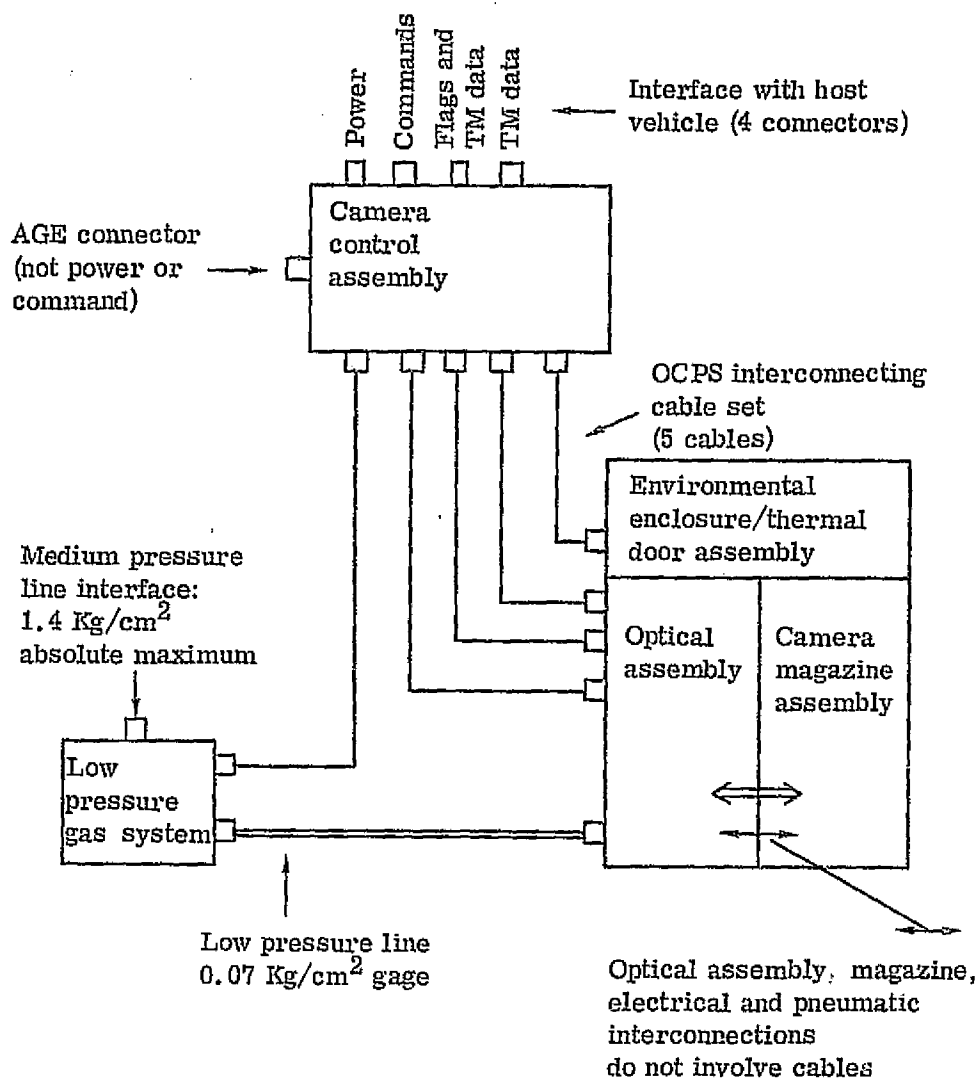


Figure 3-10 - Preliminary interconnect and interface block diagram

3.1.7 Interface Requirements

Subsequent to the definition of the overall LFC configuration, which included interface considerations, a major effort was mounted to document interface requirements. The products of this effort were the preliminary interface control documents which are identified as follows:

NASA IDC No.	Title
SLD-47-000001-801	Interface Control Document, Orbiter Camera Payload System - Functional
SLD-47-000001-802	Interface Control Document, Orbiter Camera Payload System - Mechanical
SLD-47-000001-803	Interface Control Document, Orbiter Camera Payload System - Electrical
SLD-47-000001-804	Interface Control Document, Orbiter Camera Payload System - Environmental
SLD-47-000001-805	Interface Control Document, Orbiter Camera Payload System - Film Spool (Supply and Takeup)
SLD-47-000001-806	Interface Control Document, Orbiter Camera Payload System - Installation
SLD-47-000001-901	Interface Control Document, Orbiter Camera Payload System - BTE and Ground Handling Equipment
SLD-47-000001-902	Interface Control Document, Orbiter Camera Payload System - Launch and Recovery Facilities

3.2 MISSION INTERFACE BASELINES

This section of the report discusses the work performed to demonstrate optimum LFC utilization for missions of specified nominal operating parameters. To do this, four test-case orbiter missions were selected. Three mission parameters were considered fixed. These were: mission duration, orbital inclination, and LFC film load. The four test-case missions were: first, an STS-9 mission at 28.5 degrees inclination for 5 days; second, an LFC mission at 57 degrees for 7 days; and third and fourth, LFC missions at 70 degrees and sun-synchronous inclinations for 14 days. All film loads were set at 1,220 meters.

The effects of several variables were then calculated, or made optimum. These variables, or optimized operating parameters can be grouped into two categories; i.e., those that are mission-independent, and those that are functions of the missions. The independent variables, which are discussed in detail in Section 3.2.3 are film types and exposure times. The results of our efforts here are summarized in nomographs that allow one to choose the film(s) and exposure range most suited for the Orbiter and RB-57 respectively. One might think of these variables as being mission-dependent since exposure time is governed by solar altitude, which indeed is a function of individual mission characteristics (e.g., launch time of year). However, we found that the solar altitude histograms produced for each mission are more similar, with respect to central value and distribution, than dissimilar.

The parameters that did vary more directly with each mission were: orbital altitude, launch time (of day and of year), terrain coverage and film utilization, and climatology.

Once all variables became fixed for each test case mission, a typical mission timeline was generated for each, to show thermal requirements, power consumption, and photographic opportunities. Photographic footprints for each mission were also generated and are detailed in Section 3.2.4.

3.2.1 Orbital Altitude Selection

Orbital altitude is a critical parameter for efficient LFC operation. A computer program was exercised that found the optimum altitudes for each inclination. The criteria for optimization in each case were evenly-spaced ground tracks along the equator. Thus, altitude selections were made that resulted in complete coverage of desired terrain given a sufficient mission time. Less than optimum altitudes can result in no overlap between adjacent ground tracks, which is usually coupled with several tracks over the same area (see Fig. 3-23). The optimum orbit altitudes were determined over a range from 185 to 600 kilometers. The nature of the selection process is cyclic because of the competing nature of the variables, i.e., photographic coverage increases with altitude, but so do the gaps between passes due to the longer orbit times of higher altitudes. The constant rotation of the earth versus orbital time can be used to step the ground tracks along in equal increments that ideally should be less than the photographic footprint, or this effect can cause a catastrophic no earth-satellite relative rotational movement at all. Thus, as the entire range of desired altitudes was searched for the optimum orbits a cyclic pattern of good and bad altitudes developed.

Appendix A contains optimum orbital altitudes over the 185- to 600-kilometer range for the four desired orbital inclinations, i.e., 28.5, 57, 70 degrees, and sun-synchronous. * A few test orbits for each inclination were then selected on the basis of efficiency and a customer-specified range. Table 3-1 lists the optimum altitudes and their sensitivities. Sensitivity is determined by the altitude range within which no gaps will occur in equatorial coverage. This table and the footprint data shown in Section 3.2.4 illustrate the need for close altitude tolerancing if optimum LFC operation is desired. Once an optimum altitude has been defined, achieving efficient coverage also becomes a problem of eliminating redundancy at higher latitudes. The footprint data of Section 3.2.4 reflect efforts to produce this efficient coverage.

3.2.2 Launch Time Selection

Both launch time-of-day and time-of-year were investigated with the goal of optimization for the test case missions. A computer program was exercised that calculated and plotted the central ground track for each test mission within the nominal photographic solar altitude restriction (i.e., ≥ 30 degrees). Four launch times of year, January 1, April 1, July 1, and October 1, were investigated, and launch time-of-day was varied hourly over a range of 0900 to 1500 hours. The Kennedy launch site was used for the 28.5- and 57-degree cases. Vandenberg Air Force Base was considered the 70-degree and sun-synchronous launch site.

The STS-9, 28.5-degree test mission was varied only over two dates, August 1 and October 1, due to pre-established guidelines.

Results of this exercise are delineated in Appendix B. The centers of all photographically-useful ground tracks of all above-mentioned test cases are shown.

*Appendix A also contains a graphical description of sun-synchronous polar orbit versus altitude limits.

Table 3-1 - Altitude Sensitivity

Inclination, degrees	Altitude		Equatorial Coverage Efficiency, percent	Altitude Sensitivity	
	Kilometers	Nautical Miles		Kilometers	Nautical Miles
28.5 (STS-9)	274.1	148.02	46	+0.93, -0.81	+0.50, -0.44
28.5 (STS-9)	222.7	120.26	90	+1.15, -0.56	+0.62, -0.30
57	247.0	133.69	95	+0.74, -0.11	+0.40, -0.06
57	275.9	148.97	91	+0.34, -0.30	+0.22, -0.20
57	434.0	234.33	94	+0.57, -0.37	+0.31, -0.20
70	269.5	145.54	100	+0.67, -0.04	+0.36, -0.02
70	427.5	230.84	94	+0.37, -0.44	+0.20, -0.24
96.4	221.8	119.78	93	+0.07, -0.04	+0.04, -0.02
96.6	273.7	147.79	93	+0.11, -0.7	+0.06, -0.38
97.1	421.3	227.47	90	+0.52, -0.96	+0.28, -0.52

Cases evaluated and found in Appendix B (listed by Figure Pack (FP) number) are:

Mission		Launch Time (day of year)				
Altitude, kilometers	Inclination, degrees	1 Jan. (1)	1 April (91)	1 July (182)	1 Aug. (213)	1 Oct. (274)
222.6	28.5	STS-9				
276.5	28.5				FP1	FP2
275.9	57.0	FP3	FP4	FP5		FP6
269.6	70.0	FP7	FP8	FP9		FP10
273.8	96.6	FP11	FP12	FP13		FP14

Each evaluation resulted in seven graphics showing the ground tracks over a simple Mercator projection world background. The graphics depict the effect of launch time-of-day. Depending on a mission's geographic area of priority, one can determine the most appropriate launch time throughout the year.

The primary purpose for generating these graphics was to select nominally optimum launch time-of-day. These are:

Test Mission, degrees	Launch Time-of-Day, hours
STS-9, 28.5	0900
57	1500
70	1300
96.4	1100

Optimized launch time-of-year is discussed in Section 3.2.6, Climatology in Mission Planning. The results are summarized here for continuity.

August 1 was selected as the STS-9 launch date and for which the footprints showing photographic coverage were produced (see Section 3.2.4). October 1 was selected as launch date for all other footprints and timelines. August 1 was selected because of predetermined (by NASA) schedule conditions. October 1 was selected because of a belief generated from preliminary data that this was the best time, with respect to climate, for obtaining United States coverage. The work presented in Section 3.2.6 confirmed that October is optimum for U.S. coverage, but also showed that the March to June window (with May the best) was more optimum than August for coverage of the land areas of prime interest on STS-9 (South America, Africa, Australia, and the India-Malaysian area).

In summary, optimum launch times-of-day have been selected for use in the test mission cases. Near optimum launch times-of-year have been identified, but have not been used for all test cases due to preimposed schedule restraints. The climatology data in Section 3.2.6 allows for tailoring launch times-of-year to specific photographic target areas.

3.2.8 Exposure Time and Film Type Selection

This exercise was designed to produce a choice of optimum films and exposures for the LFC/Orbiter and LFC/RB-57 missions. The prime variables that affect this selection are: ground scene reflectance, vehicle motion, and solar altitude.

Figs. 3-11 to 3-14 show histograms of experienced solar altitudes for the four test case missions produced by the computer programs that generated all footprint data for these missions. These figures can be used to derive a mean expected solar altitude for exposure calculation. Note that this mean, for exposure prediction purposes, is on the order of 50 degrees. Also note that the program that produced this solar altitude data could be made to do so on a real-time operational basis for single-frame exposure control.

Fig. 3-15 illustrates the results of exposure prediction analyses for candidate LFC films. The use of this nomograph allows the prediction of exposure time for given solar altitude conditions and an average (12 percent) scene reflectance. Subject contrast on the original film materials can also be predicted by reference to the materials' illuminance axis. Given the known scene reflectance values as a function of solar altitude as shown on the left-side graph, the nomograph is simply a graphical solution to the image irradiance equation:

$$H' = \frac{H T_0}{4(f/\text{no.})^2 (FF)}$$

where:

- H' = image irradiance
- H = object irradiance (Hyperaltitude, at the lens)
- T₀ = lens transmission factor = 0.25
- f/no. = f/number of the LFC=6
- FF = filter transmission reduction factor

Given a desired density level on a candidate film, the required exposure in meter-candle-seconds can be determined from the D-log E curve, and the required exposure time is found finally from the nomograph.

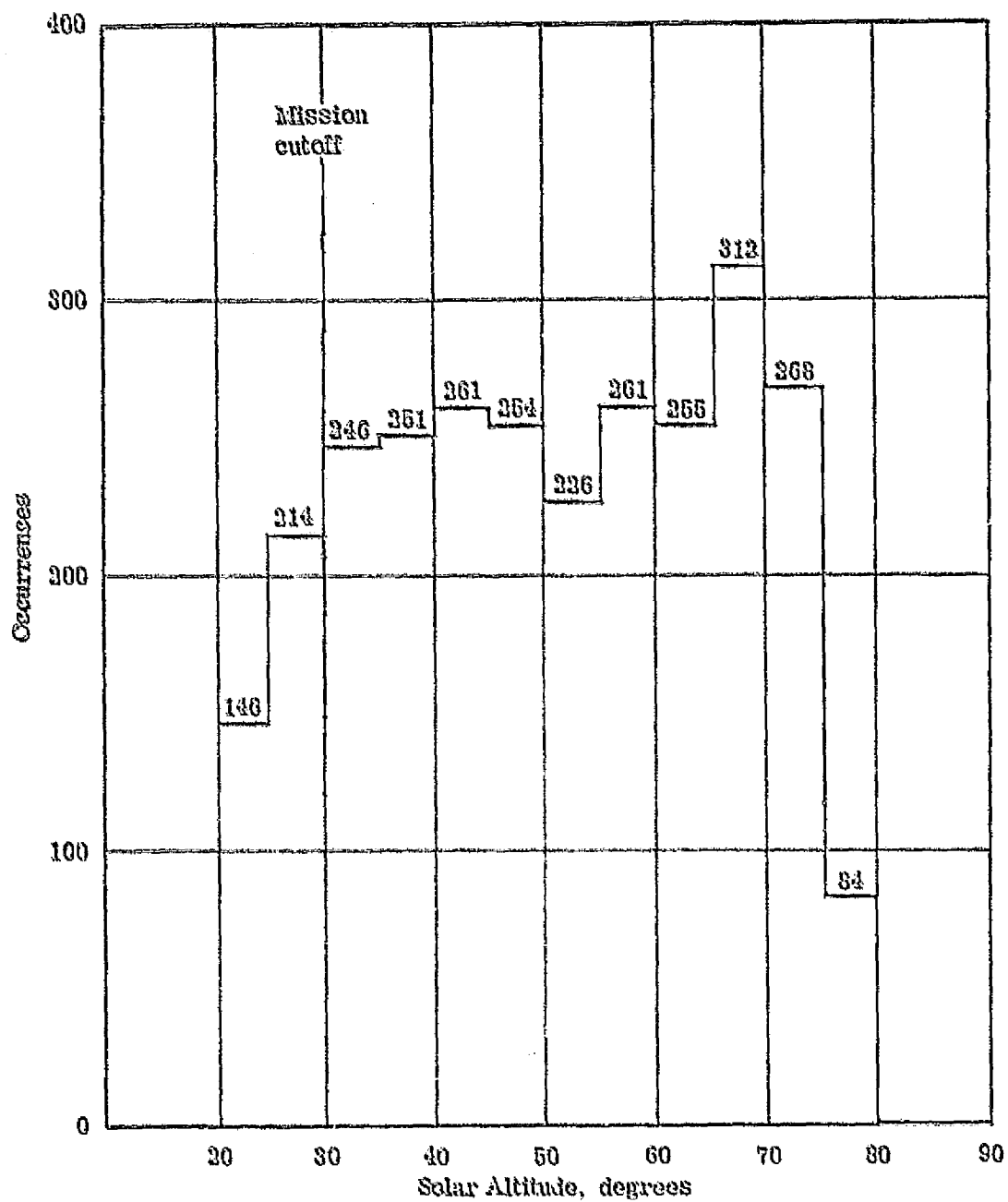


Figure 3-11 - Solar altitude histogram: STS-9 mission, inclination 28.6 degrees, launch date 1 August, launch time 1300 hours

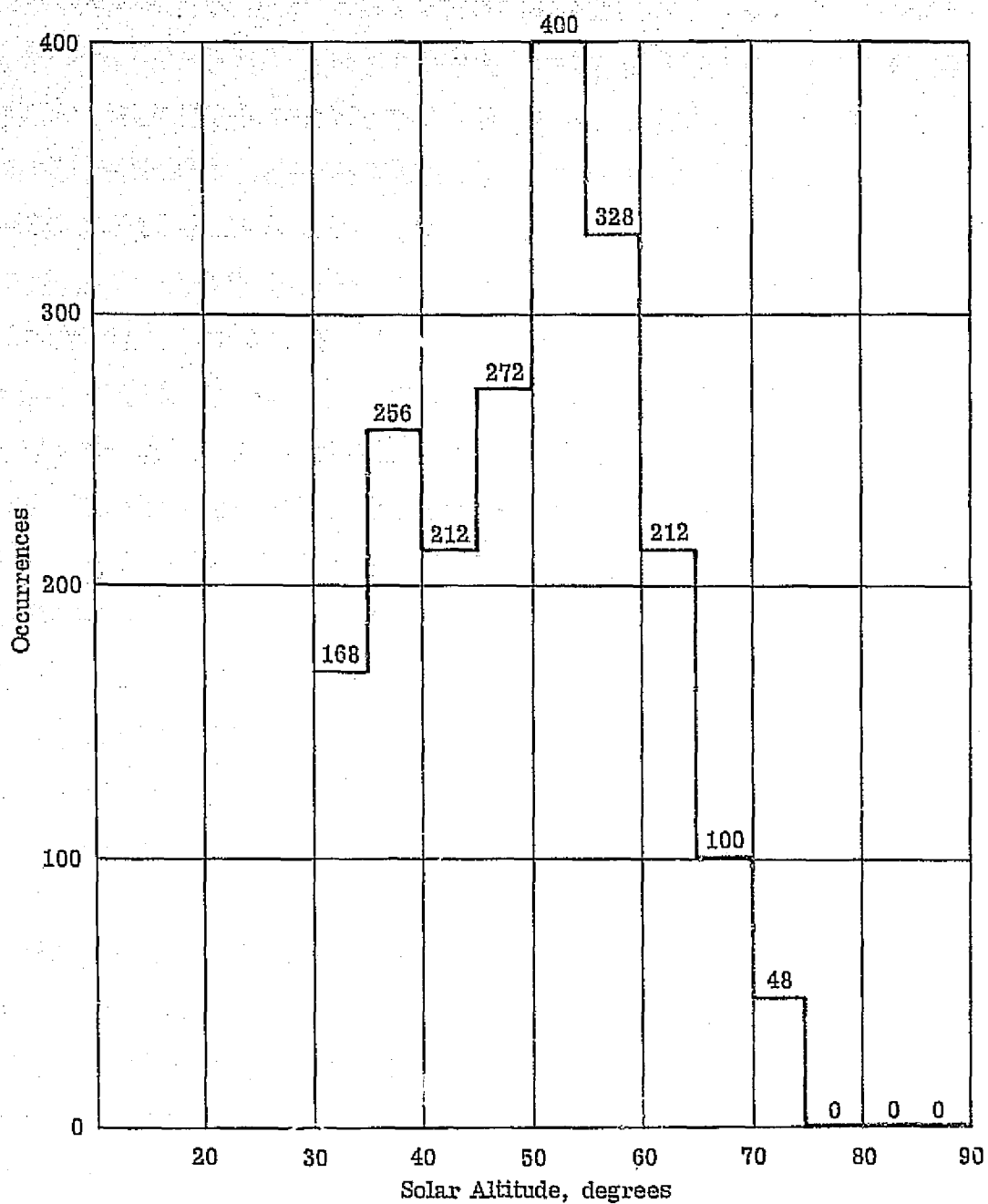


Figure 3-12 — Solar altitude histogram: LFC mission, inclination 57 degrees, launch date 1 October, launch time 1500 hours

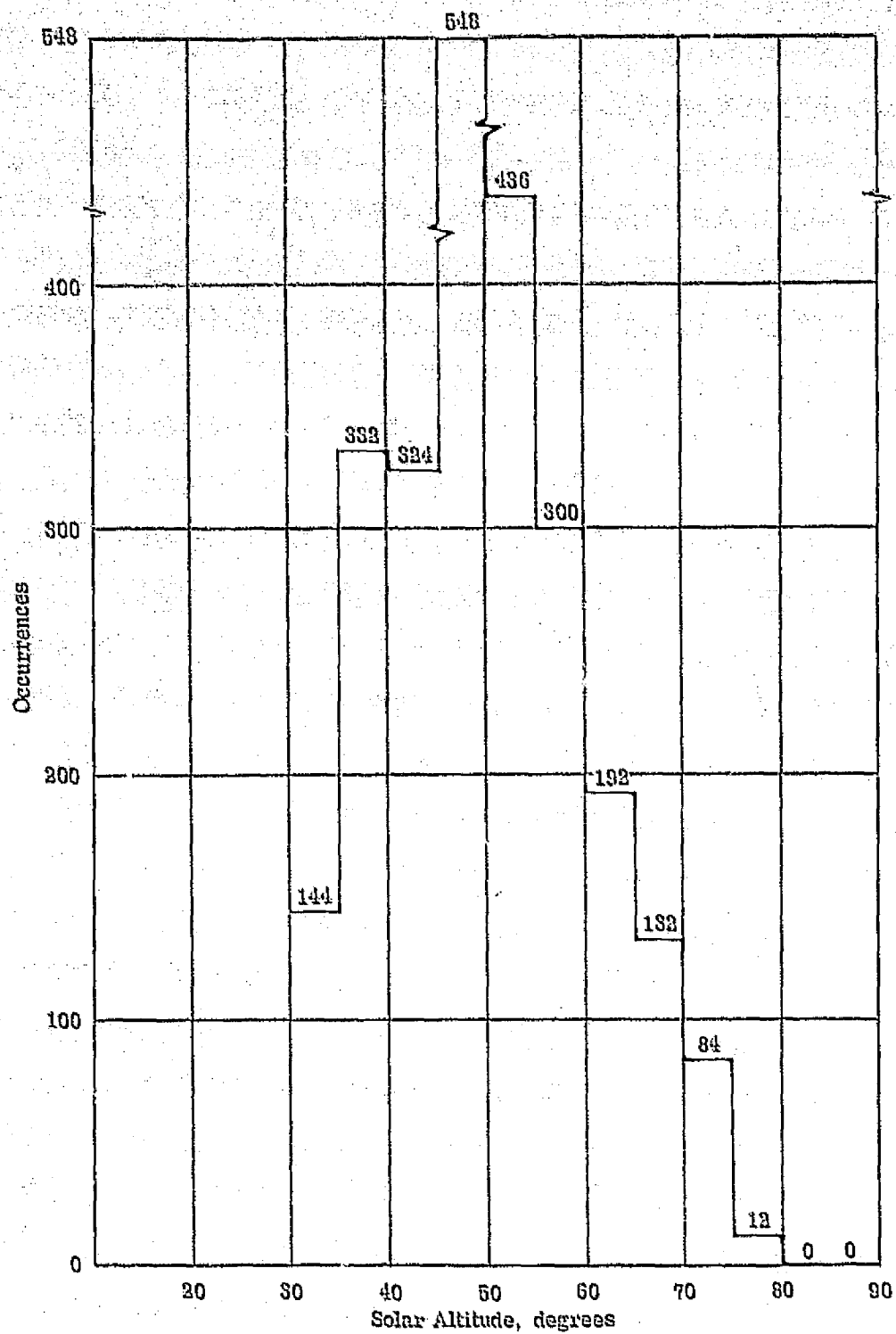


Figure 3-13 — Solar altitude histogram: LFC mission, inclination 70 degrees, launch date 1 October, launch time 1500 hours

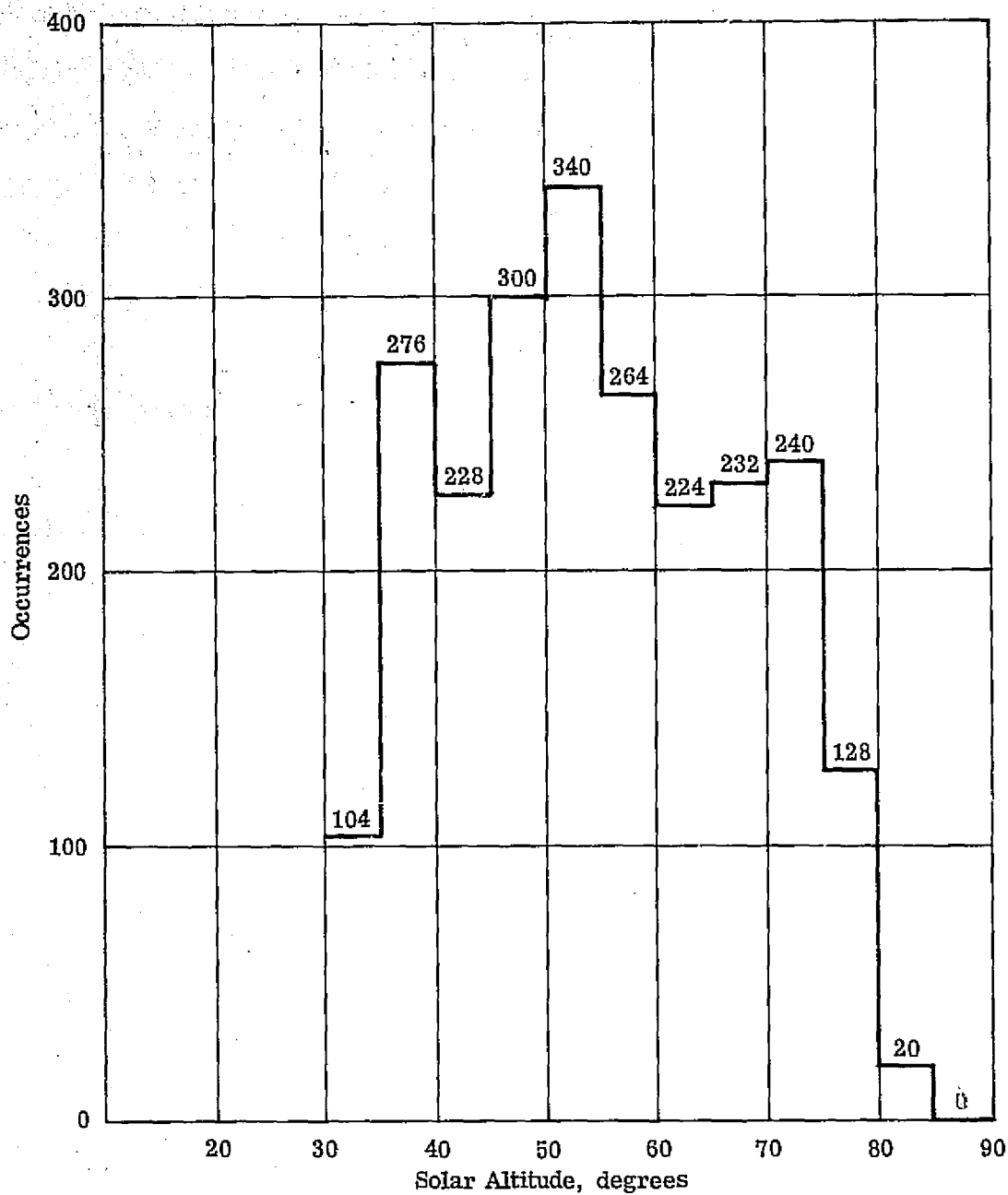


Figure 3-14 — Solar altitude histogram: LFC mission, inclination 96.6 degrees, launch date 1 October, launch time 1100 hours

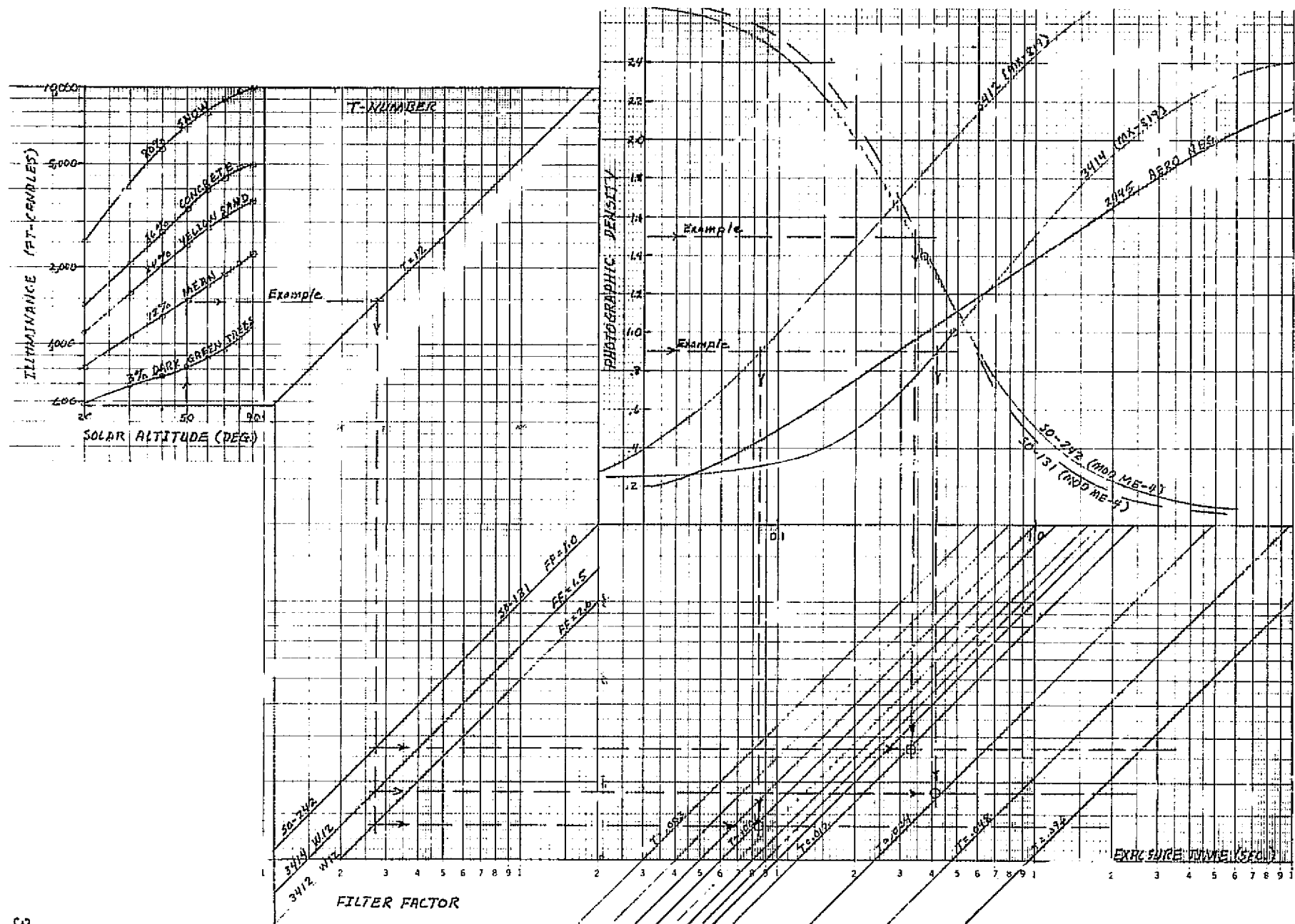


Figure 3-15 - NASA-LFC exposure time prediction nomograph

For example, target densities of 0.9 for negative films and 1.5 for reversal materials are accepted standards. It can be seen by following the illustrations, 0.43 meter-candle-second is the required exposure for 3414 film, which results in an exposure time of approximately 24 milliseconds if a 50-degree solar altitude is assumed.

Using Fig. 3-15, a relational equation between solar altitude and exposure time can then be developed for real-time numerical computation prediction. A different equation must be developed for each film and for the 3414 film example this is:

$$ET = 10^x \text{ (msec)}$$

where:

$$x = 2.511 - 0.676 \log_{10} (SA)$$

and solar altitude (SA) is in degrees.

The goal of this effort was to select the film(s) that would produce the best LFC image resolution. The first step was to take the candidate films shown in Fig. 3-15 and develop exposure time requirements. The second step was to calculate expected dynamic resolutions for each film-dynamic condition combination.

To do this, expected Orbiter and RB-57 attitude rates were used to calculate motion-limited resolution values. Static resolution values were calculated for each lens/film combination by application of the "reciprocal resolution squared" relation. Finally, dynamic resolution values were derived by applying this same relation to each static/dynamic combination of interest. The result is a series of three nomographs that have been developed to produce a film selection guide that is used by considering illumination conditions and attitude stability rates.

Fig. 3-16 relates to the Orbiter/LFC combination. In this nomograph, exposure time and expected attitude rates are employed along with film-plus-smear limiting resolution curves to allow the prediction of dynamic resolution for each film type. Fig. 3-17 is a similar nomograph that relates to the RB-57/LFC mission combination. Combining the data from Figs. 3-16 and 3-17, while modifying the shapes of the limiting resolution curves on the basis of relative exposure times (from Fig. 3-15), allows the generation of a nomographic guide for the selection of the film type to be used for maximum resolution performance when expected solar altitude and vehicle attitude rates are established. Fig. 3-18 presents this nomograph. The order of merit of the film types at the bottom of the figure are defined as a consequence of operational conditions.

Table 3-2 shows each step of the selection process for all candidate films for nominal (as defined in the table) operating conditions.

The following constants were used to produce the dynamic resolution values of the table:

Orbiter smear rate = $\dot{\alpha}$ = 0.18 mrad/sec

RB-57 smear rate = $\dot{\beta}$ = 2.5 mrad/sec

LFC focal length = 305 mm = f

LFC AWAAR lens resolution = 84 cycles/mm

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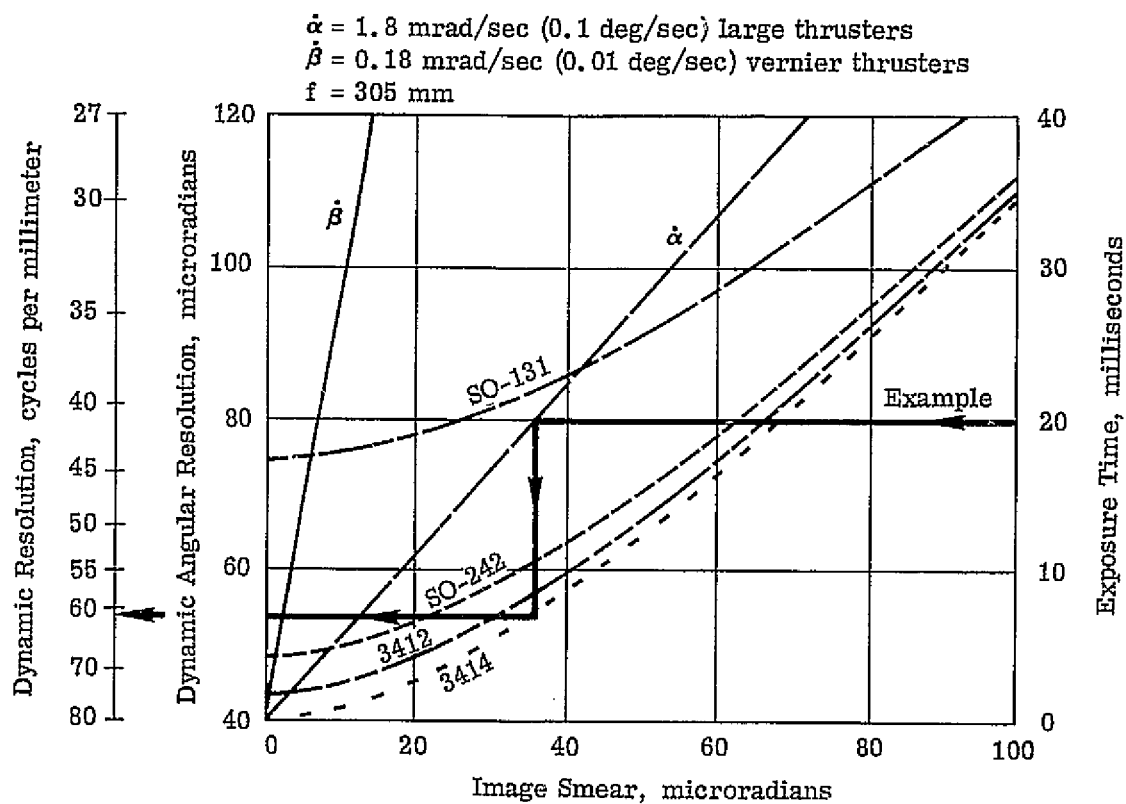


Figure 3-16 - Dynamic resolution prediction nomograph-Shuttle Orbiter/LFC

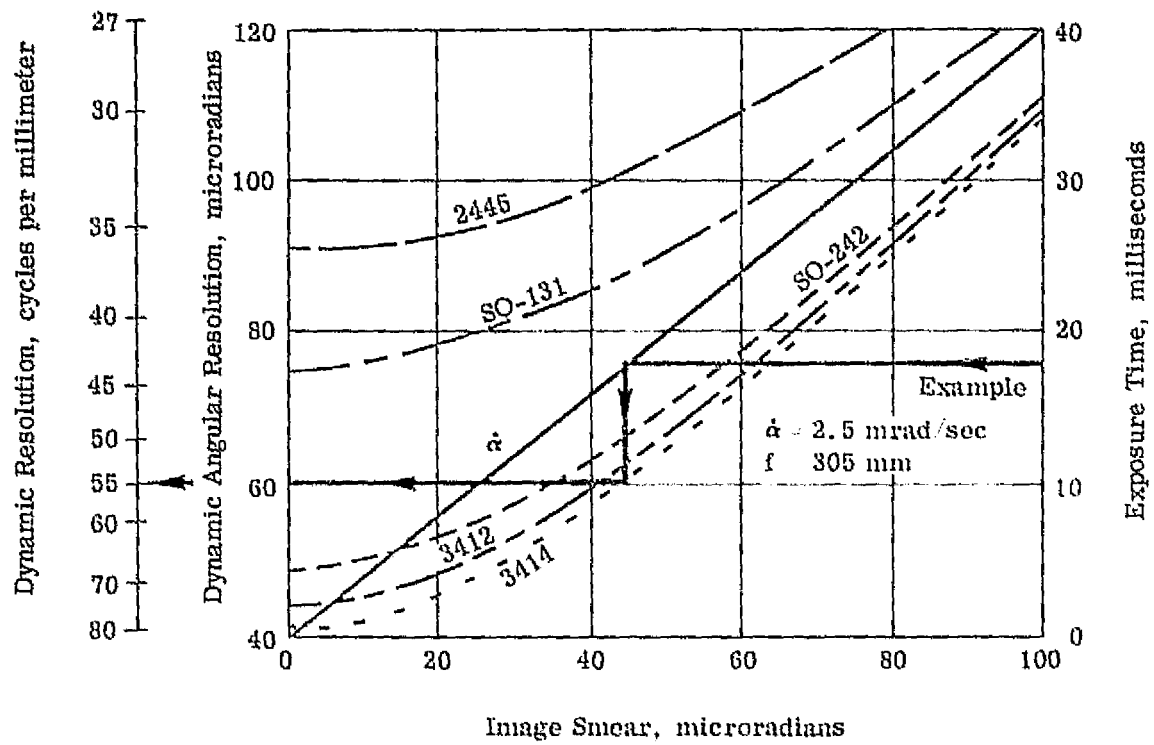


Figure 3-17 - Dynamic resolution prediction nomograph-RE-57 LFC

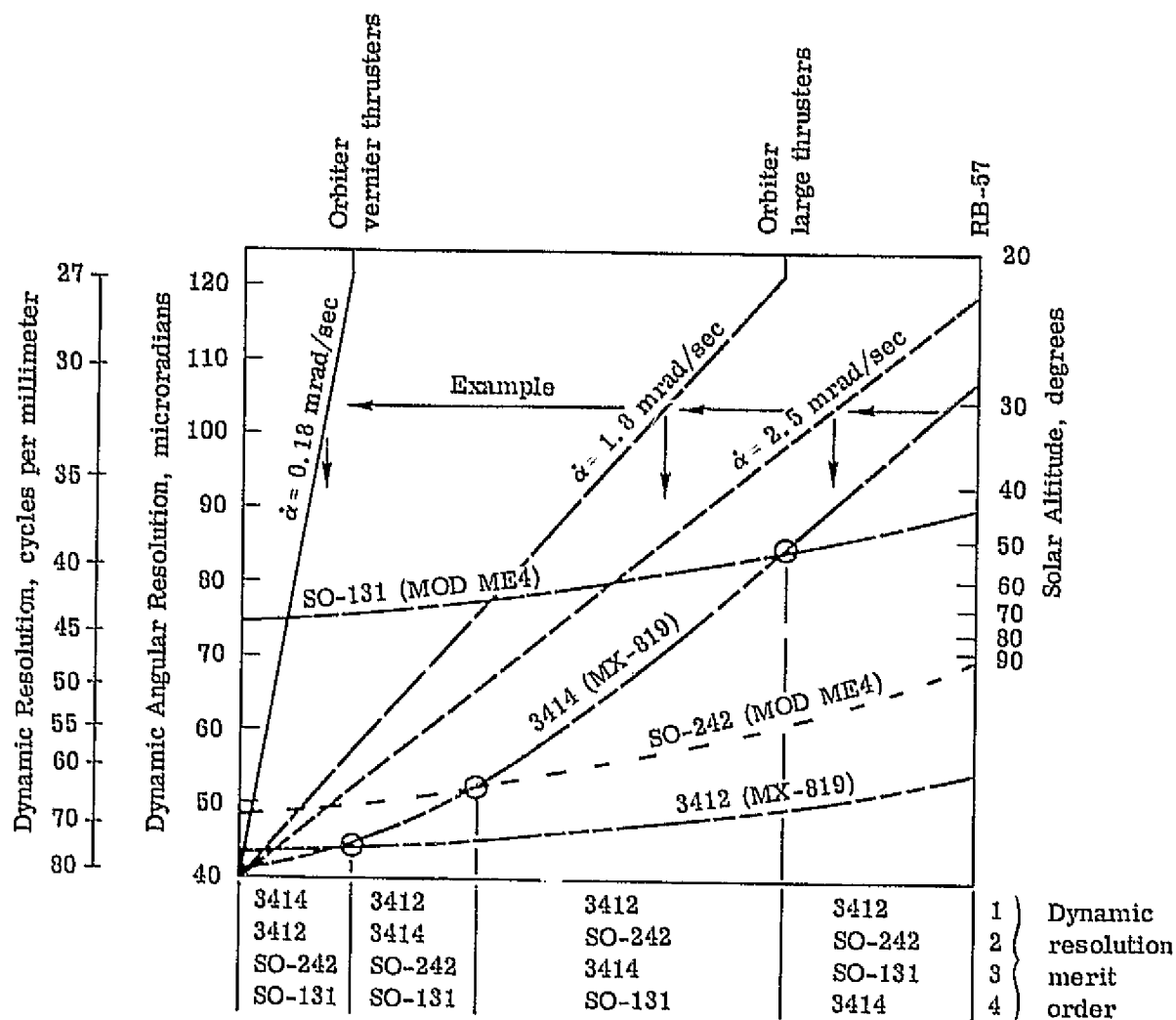


Figure 3-18 - LFC film selection guide

The general case for image smear (v) where

$$v = \left[(\dot{\alpha} f \tan \theta)^2 + \left(\frac{\dot{\alpha}' f}{\cos^2 \theta} \right)^2 + \left(\frac{\dot{\alpha}'' f}{\cos^2 \theta} \right)^2 \right]^{1/2}$$

was simplified to the on-axis image smear condition for the dynamic resolution predictions.

In summary, no one film is optimum under all conditions. The 3412/SO-242 film combination appears best for general-purpose applications.

Table 3-2 - Resolution and Exposure Parameters - STS-9*

Film Type	Exposure Time, msec	Shuttle/RB-57 Image Smear, cy/mm	Film Resolution	Static Resolution	Shuttle/RB-57 Dynamic Resolution, cy/mm
			Limit 1.6:1 contrast, cy/mm		
SO-315	26.8	513/49	441	83	82/42 [†]
3414	24.6	559/53	255	80	79/44, 70 [§]
3412	6.5	2,118/202	160	74	74/69
SO-242	16.1	855/82	110	67	67/52
SO-131	17.2	800/76	51	44	44/38
2445	16.1	855/82	40	36	36/33
2448	20.3	690/66	40	36	36/32
3443	13.8	1,000/95	32	30	30/29

*For solar altitude = 50 degrees

[†]For corrected LFC transmission function

[§]For high gamma, (2.5), MX-641 processing

3.2.4 Terrain Coverage and Film Utilization

Photographic footprint plots are presented in this section for each test case mission. Vital parameters of each mission are summarized in table 3-3, and accompany each footprint plot.

Table 3-4 provides a more detailed mission profile for STS-9, in which the photographic restrictions are shown.* Photographic restrictions are not as stringent for all other missions where 3 revolutions at the beginning and 5 revolutions at the end of each mission were not allowed for photo operations.

*Note that the first altitude of the STS-9 mission (274.1 km) is not very efficient (see Table 3-1) but is quite adequate for this limited duration mission in which closure is not achieved due to a time limit.

Table 3-3 - LFC-Orbiter Test Case Mission Parameters

Mission	Inclination, degrees	Altitude, kilometers	Stereo Overlap, percent	Launch Date	Time, hours	Duration, days
STS-9	28.6	274.1	80	1 August	0900	6
	28.6	222.6	80/80			
Second	57	275.9	80	1 October	1500	7
Third	70	269.6	80	1 October	1300	14
Fourth	96.6	273.7	80	1 October	1100	14

Table 3-4 - STS-9 Mission Profile

Day	Time	Activity	Revolutions
1.0	First 24 hours	Satellite deployment	16
2.0	Second 24 hours	Photo operations	16
3.17	4 hours	Altitude change	2.7
3.0	20 hours	Photo operations	13.5
4.0	24 hours	Photo operations	16
4.69	16.6 hours	Photo operations	11.2
5.0	7.4 hours	Descent	5

In each case, the footprint program was exercised with the objective of near full utilization of the 1,220-meter film load.

Figs. 3-19, Sheets 1 through 5, show anticipated coverage for STS-9 on a daily and cumulative basis. Figs. 3-20 through 3-22 show cumulated coverage for the 57-, 70-, and 96.6-degree test missions respectively. It is noted that prime geographic coverage for each of these test cases after STS-9 was the continental United States landmass. Other areas were included to illustrate potential mission coverage capabilities. Some film remained unexpended in each case to allow for acquisition of photo opportunities of interest.

All show the LFC footprints overlayed on a worldwide Mercator projection.

In Sections 3.2.1 and 3.2.2, the necessity of carefully-chosen orbital altitude and launch times was discussed. Figs. 3-23 and 3-24 illustrate the need for care in choosing these parameters. Fig. 3-23 shows a 70-degree inclination mission with identical parameters to Fig. 3-21, except for an altitude of 11 kilometers lower than the optimum. The same areas are covered repeatedly with large gaps in-between, but the full film load is spent. Fig. 3-24 shows the effect of launching at the wrong time of day, i.e., 1500 hours as opposed to 1100 hours for the optimum 96.6-degree inclination mission.

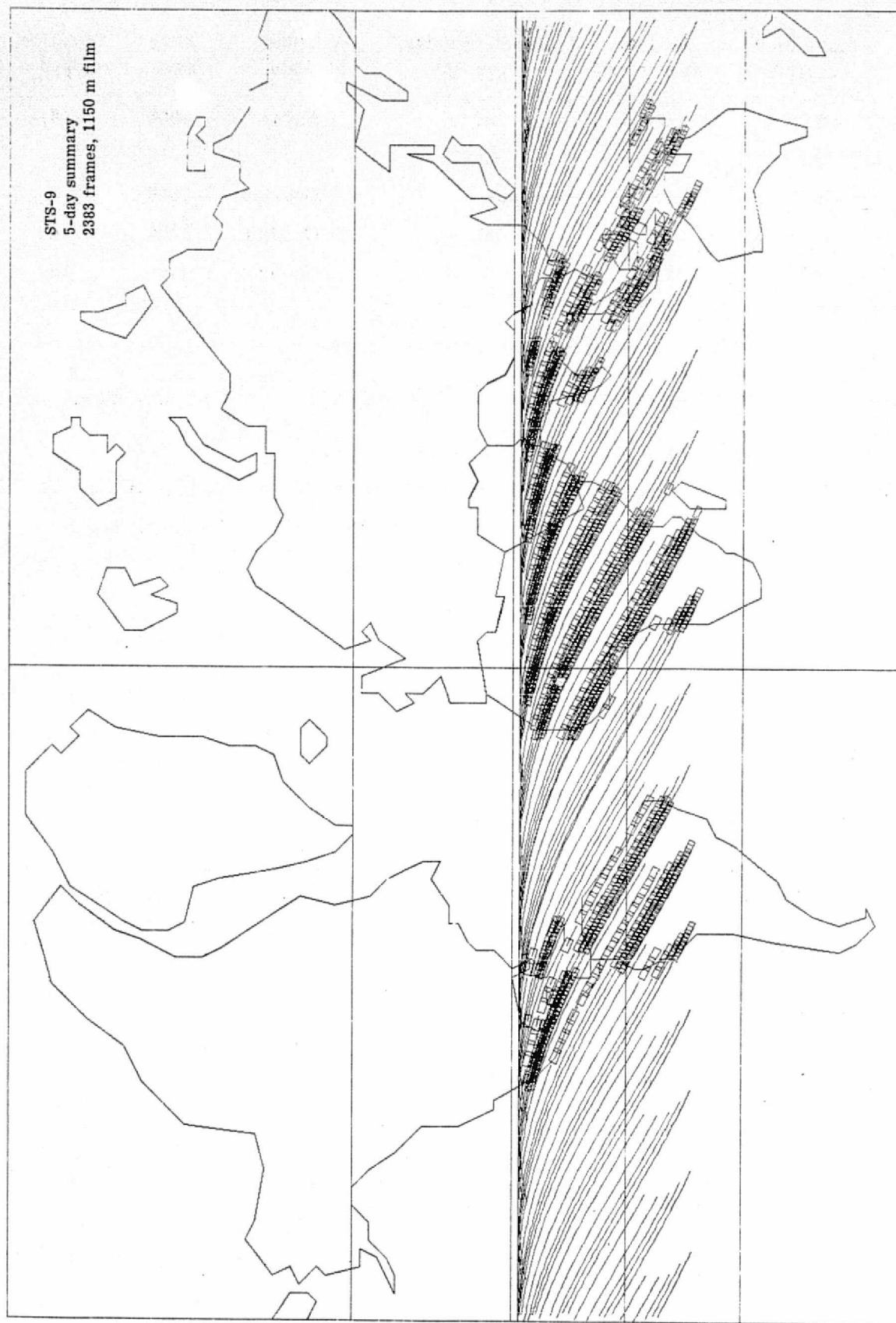


Figure 3-19 -- STS-9 mission daily and cumulative photographic coverage and film usage
(Sheet 1 of 5)

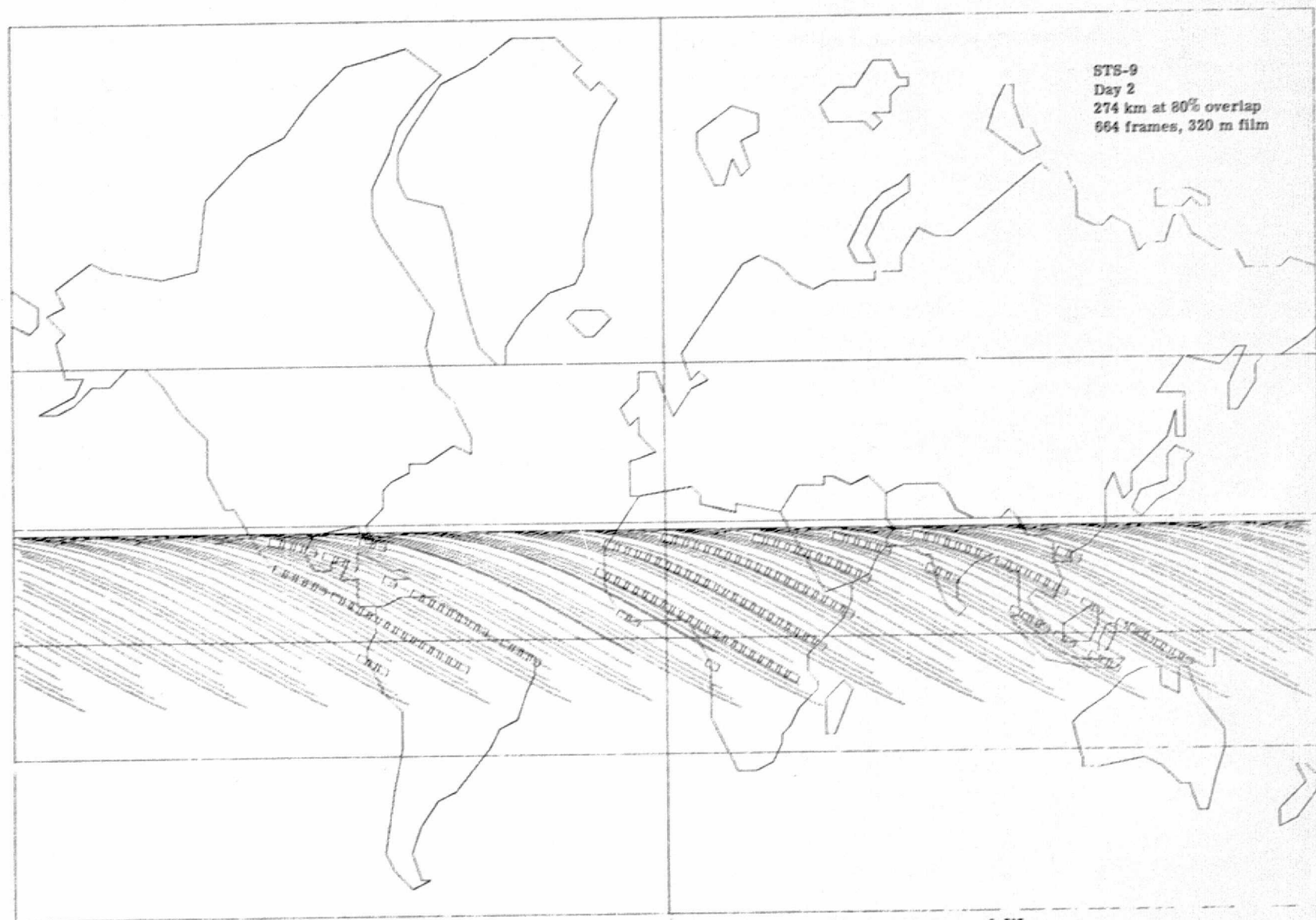


Figure 3-19 - STS-9 mission daily and cumulative photographic coverage and film usage
(Sheet 2 of 5)

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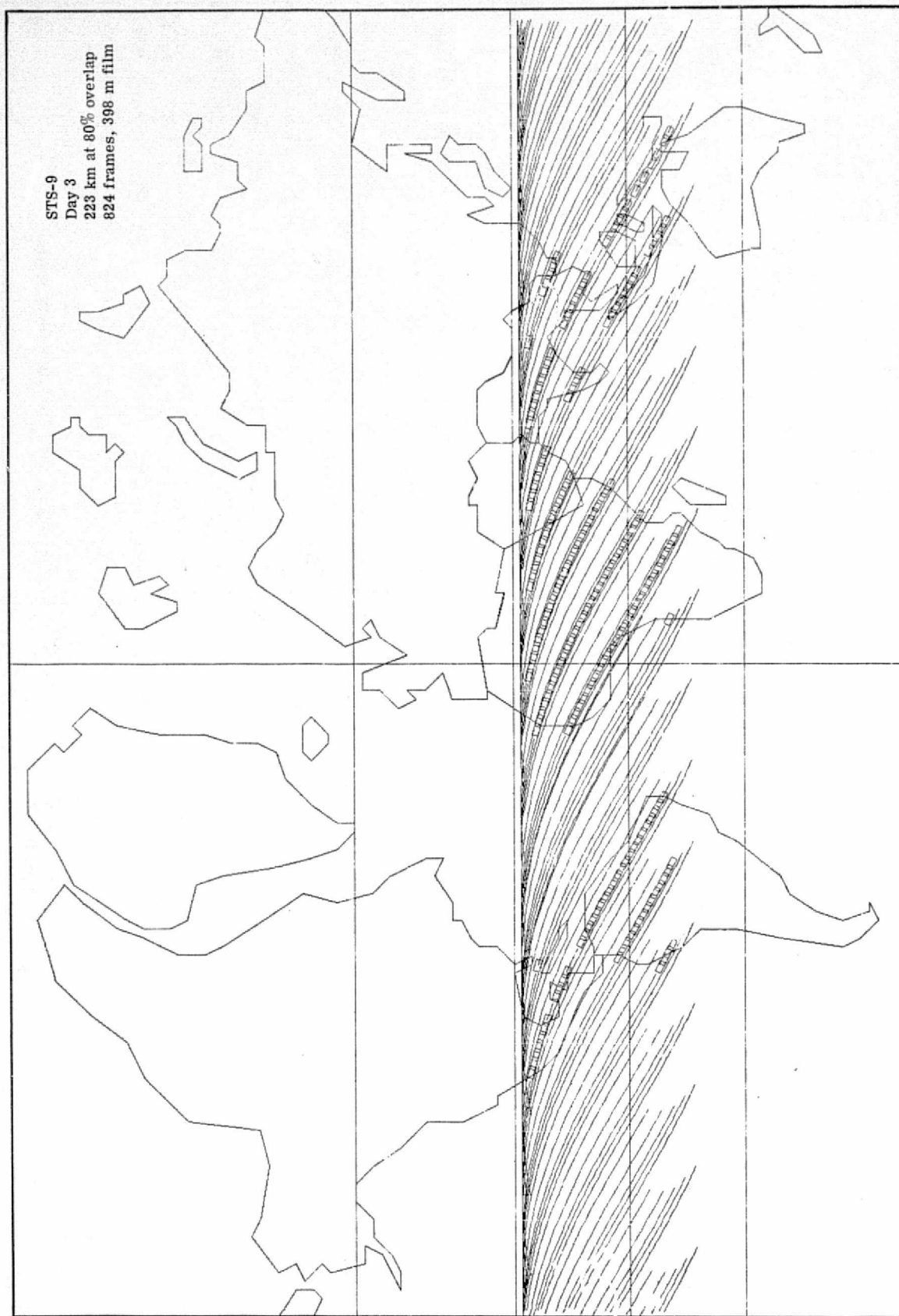


Figure 3-19 - STS-9 mission daily and cumulative photographic coverage and film usage
(Sheet 3 of 5)

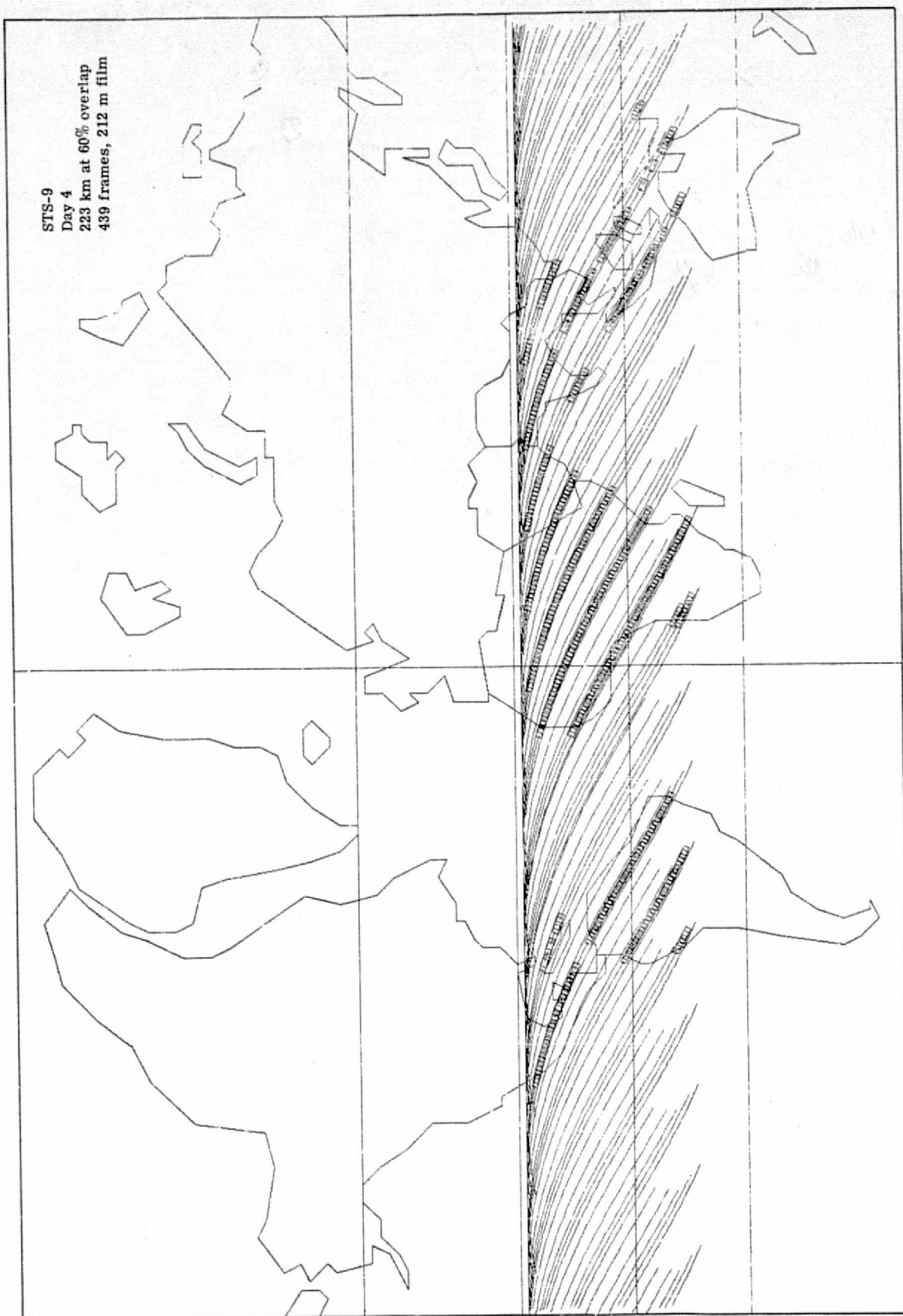


Figure 3-19 - STS-9 mission daily and cumulative photographic coverage and film usage
(Sheet 4 of 5)

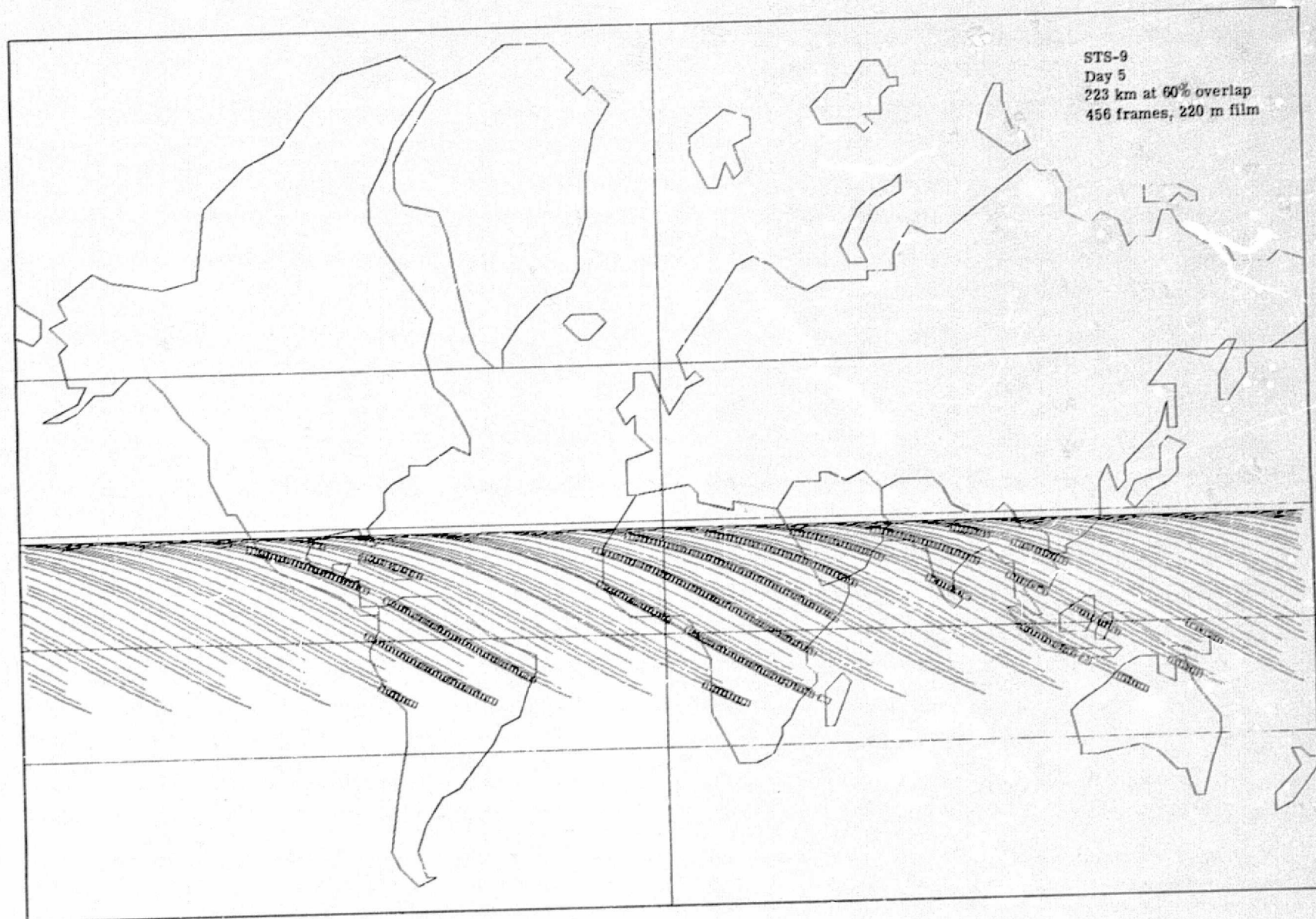


Figure 3-19 - STS-9 mission daily and cumulative photographic coverage and film usage
(Sheet 5 of 5)

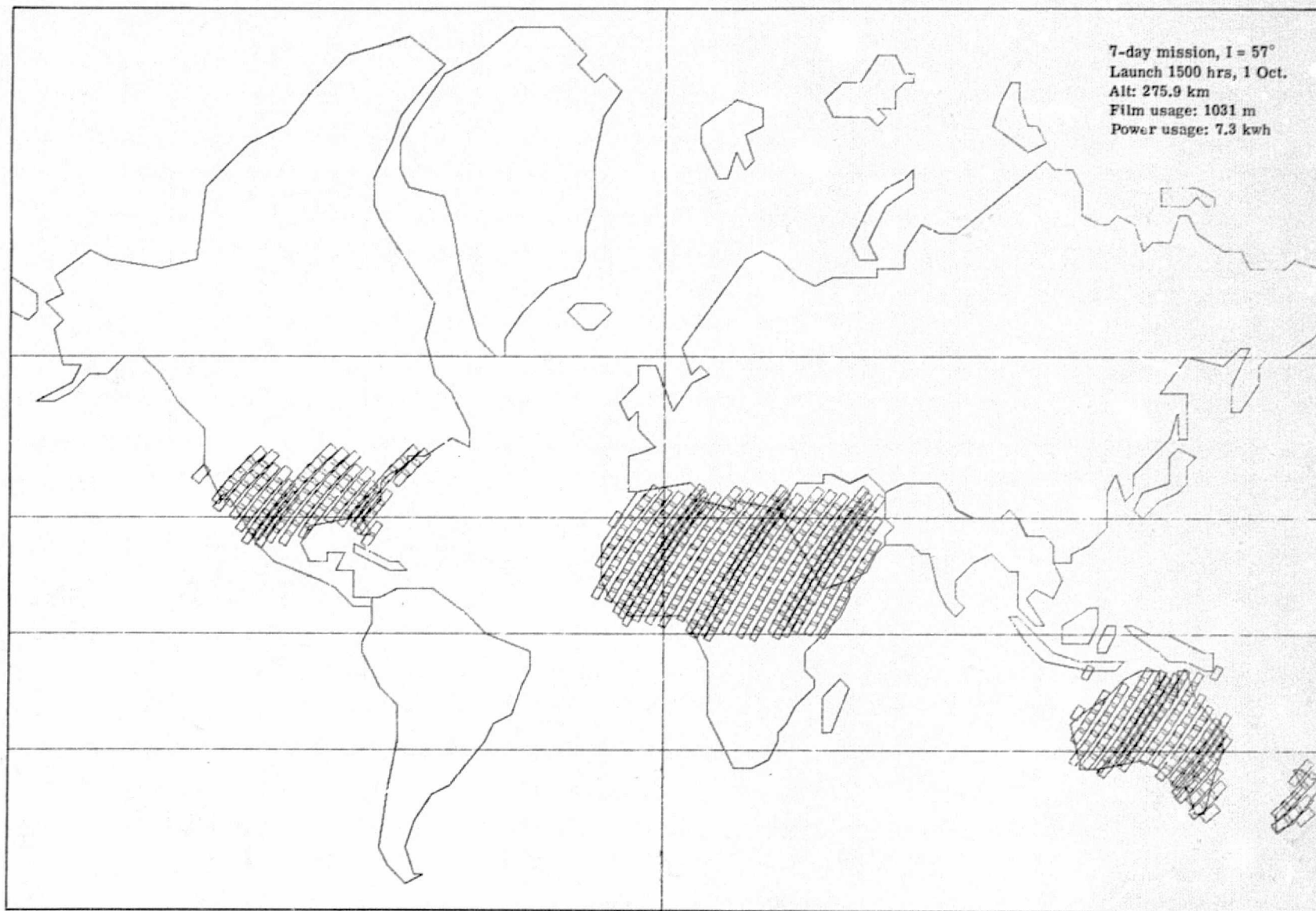


Figure 3-20 - Cumulated coverage for LFC 7-day mission, inclination 57 degrees

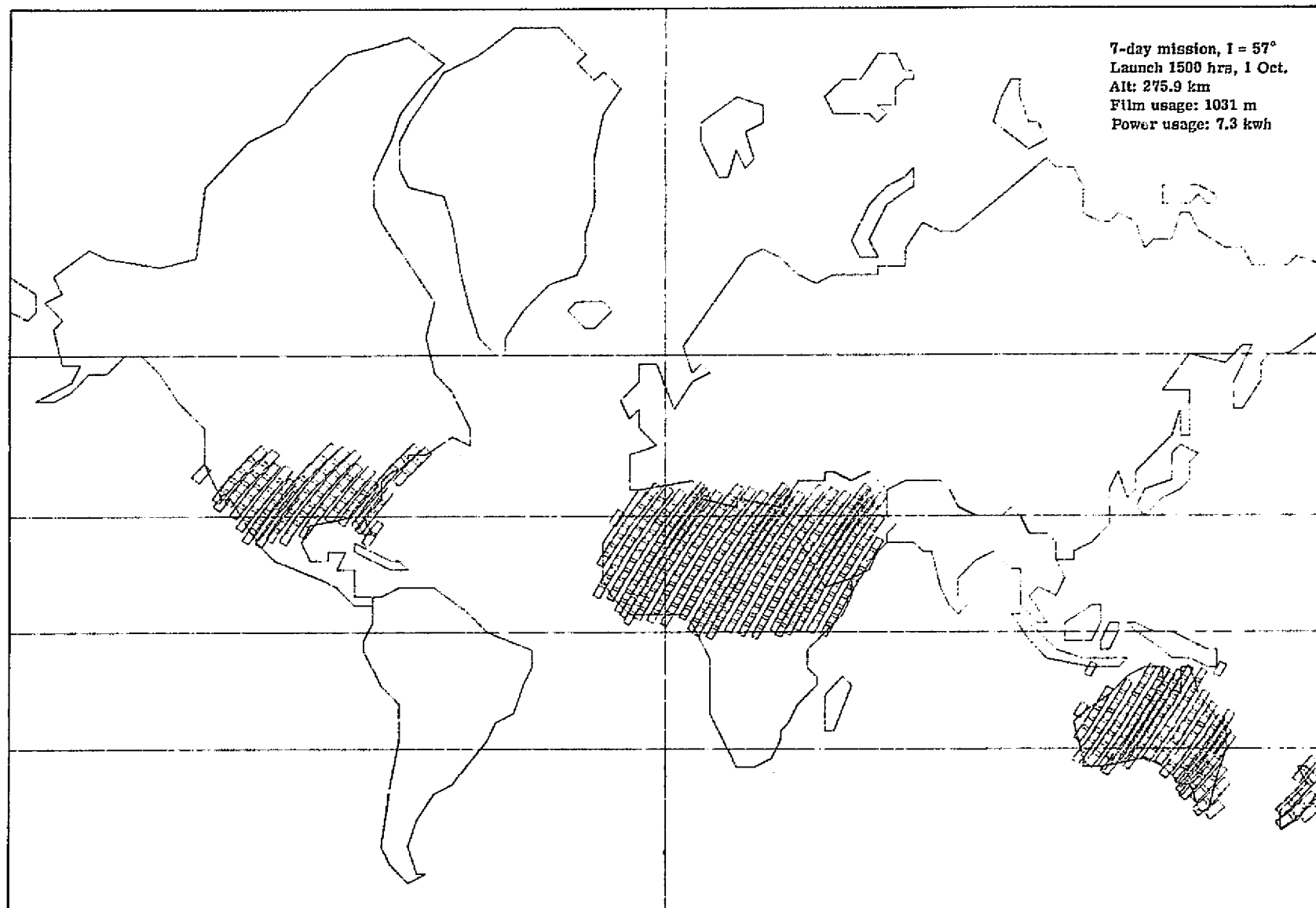


Figure 3-20 - Cumulated coverage for LFC 7-day mission, inclination 57 degrees

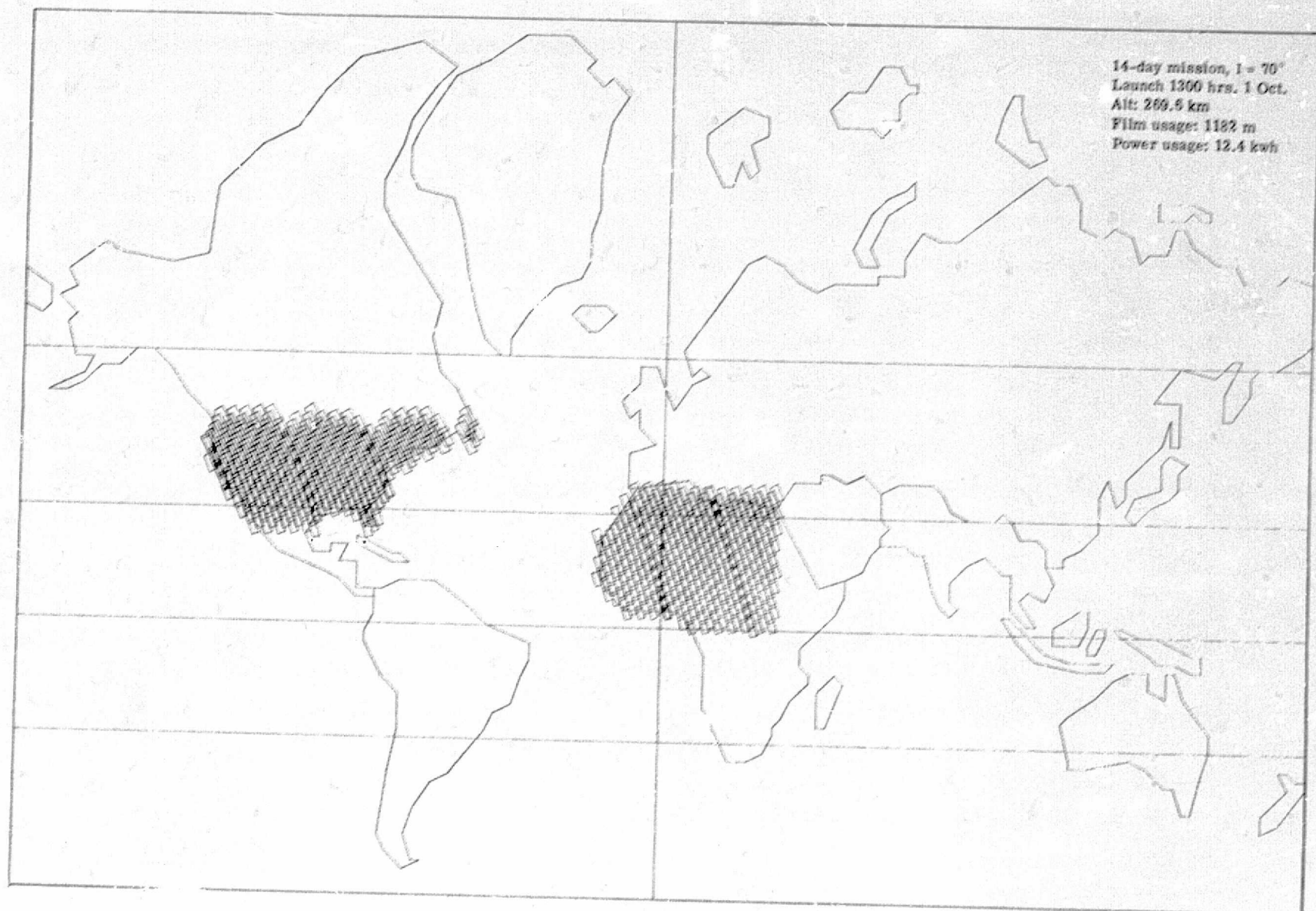


Figure 3-21 - Cumulated coverage for LFC 14-day mission, inclination 70 degrees

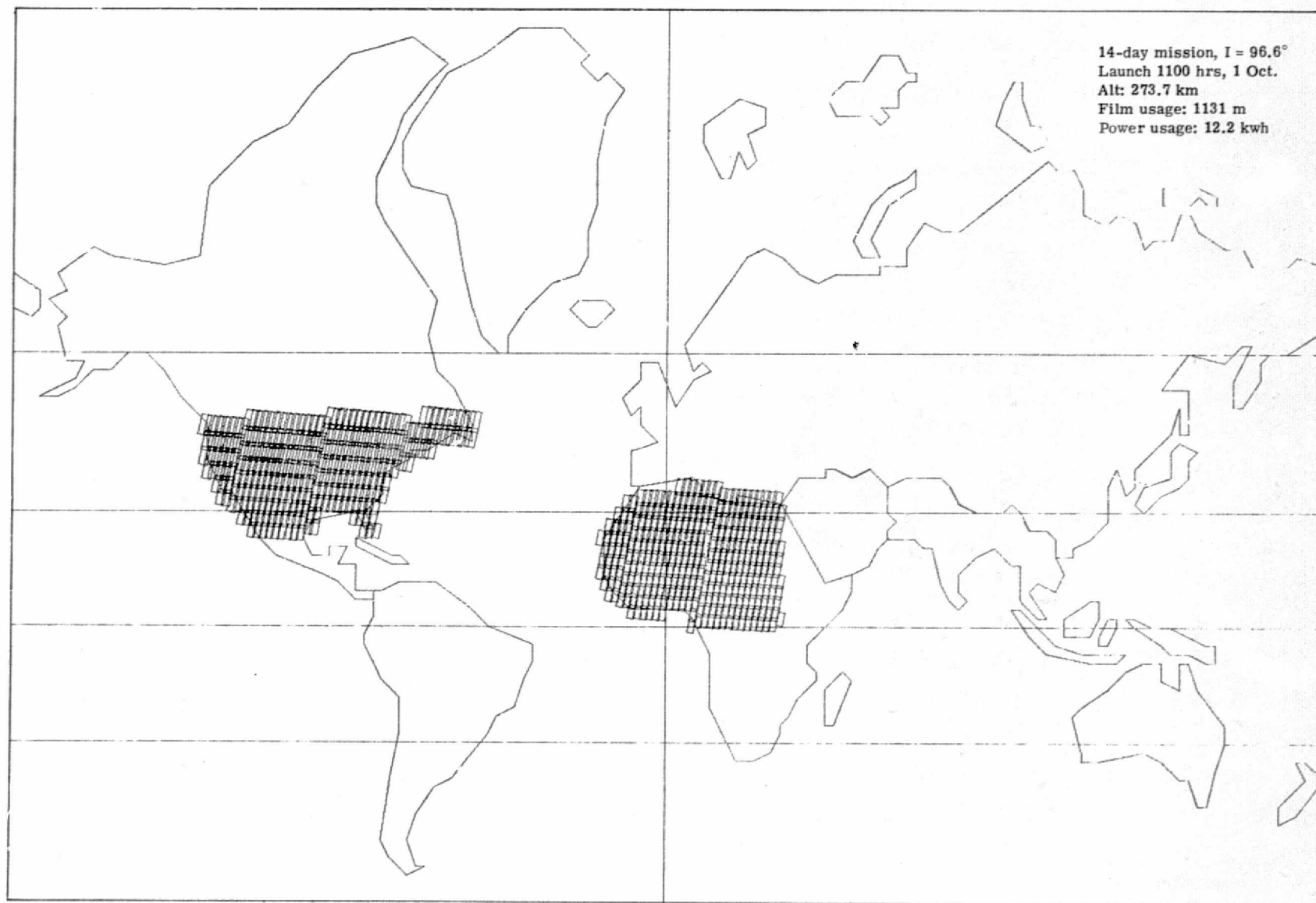


Figure 3-22 - Cumulated coverage for LFC 14-day mission, inclination 96.6 degrees

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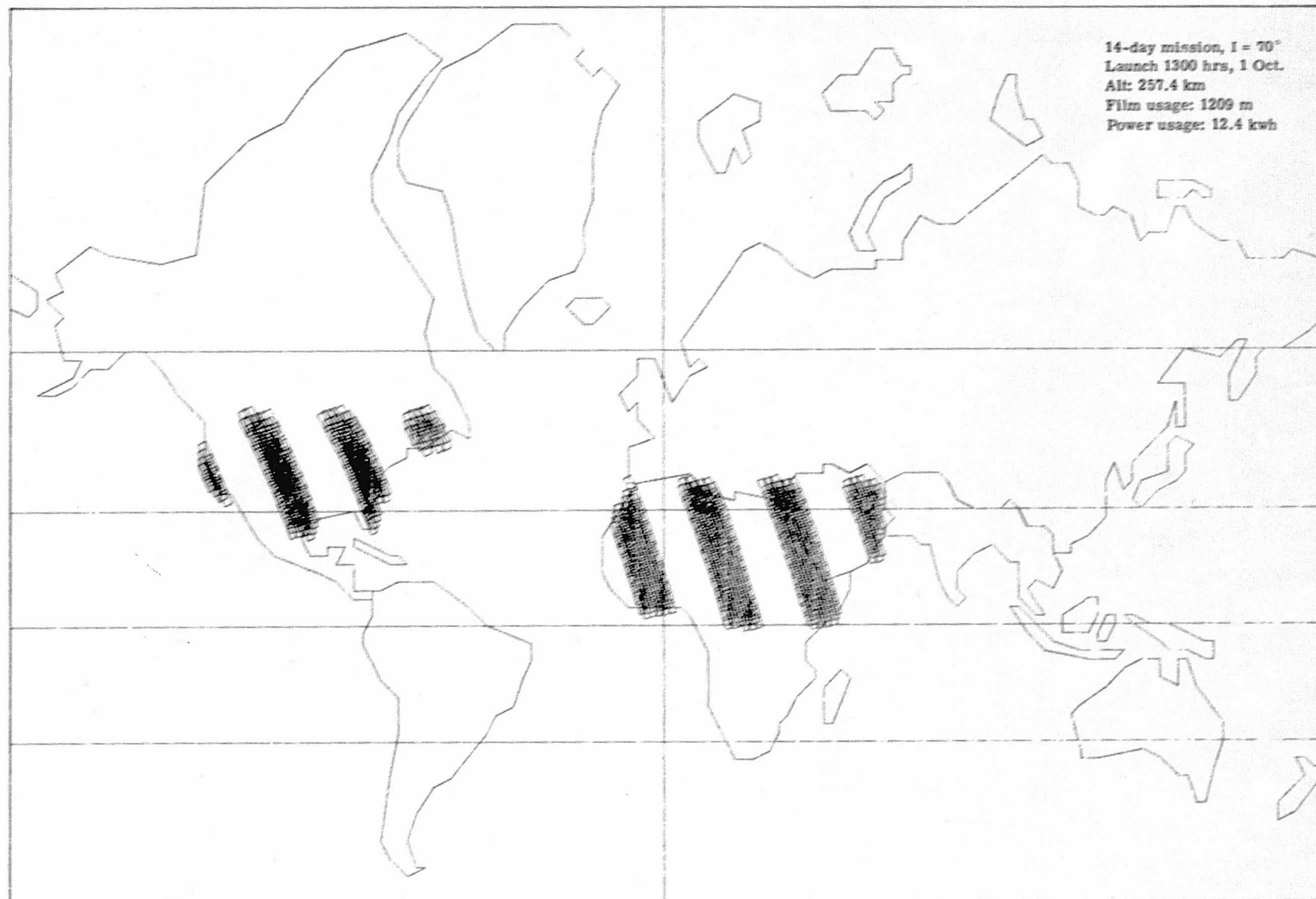


Figure 3-23 - Cumulated coverage for LFC 14-day mission, inclination 70 degrees

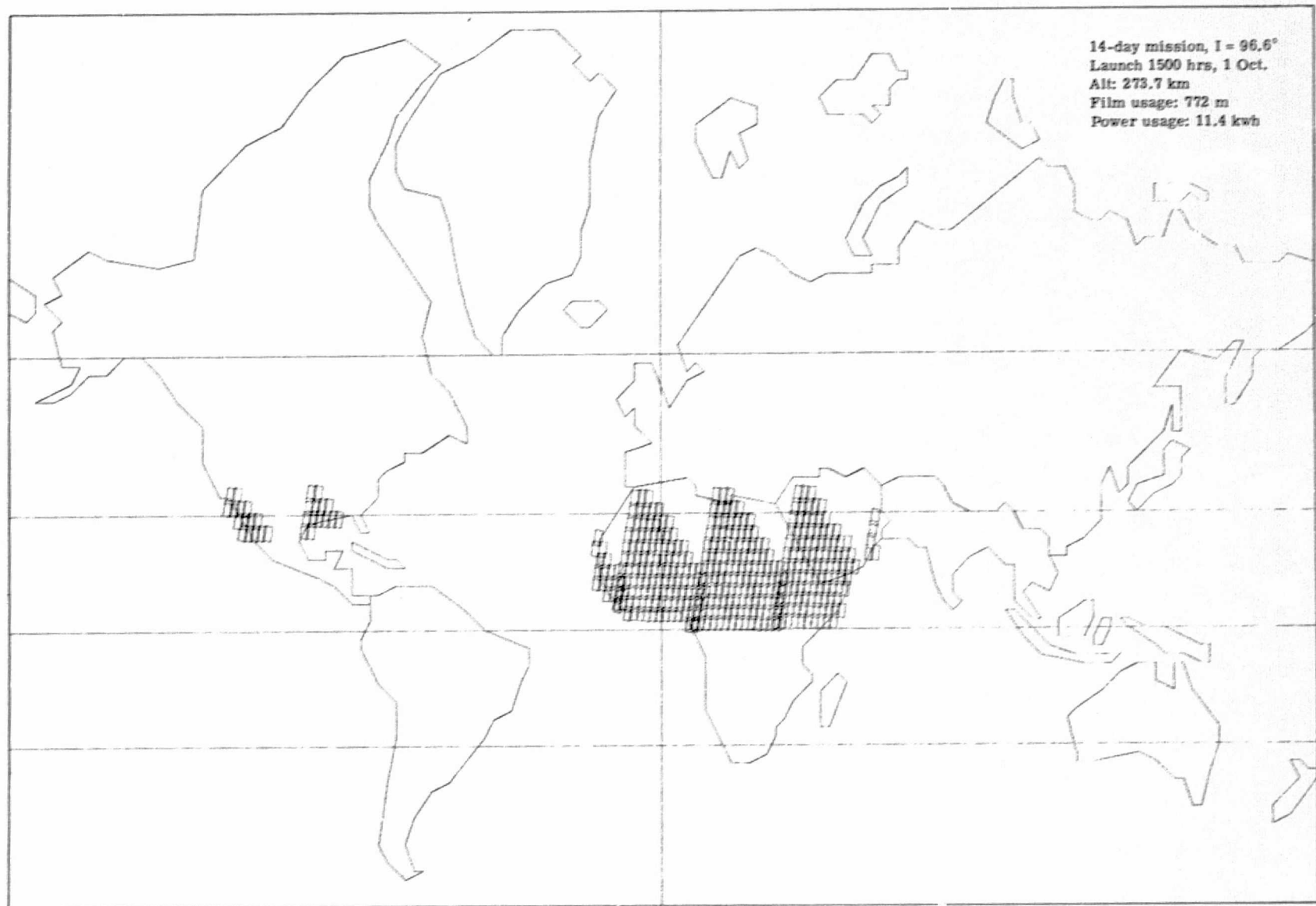


Figure 3-24 - Cumulated coverage for LFC 14-day mission, inclination 96.6 degrees

3.2.5 Test Case Mission Timelines

The computer program that generated the LFC footprints also produced key mission data in tabular form at intervals equivalent to individual camera operations over the entire mission. This data was used to produce test case mission timelines. These are shown in Figs. 3-25, 3-26, 3-27, and 3-28. Each shows every orbit revolution on a sequential time axis with the following data displayed:

1. Time of all photographic opportunities
2. Time in sunlight during each orbit for heater power consumption planning
3. Crew preparation and participation times associated with each photographic opportunity
4. Power consumed (cumulative) at 24-hour intervals
5. Vital mission statistics also presented in the previous section (e.g., altitude, inclination, and launch time)
6. Mission hours, days, and crew local time.

In summary, these timelines provide data relevant to advanced mission planning in a usable format. Additional data of interest, such as geographic location of each photographic opportunity, could also be displayed in this form with relative ease.

3.2.6 Climatology in Mission Planning

All previous tasks have produced optimized photographic coverages and have done so only on consideration of key mission parameters. These "footprint" results have demonstrated full utilization of LFC film loads over the target areas of maximum interest within the allotted mission time limits and solar altitude conditions. The effort reported hereunder was designed to acquire climatological data that can bear directly on mission efficiency and completion. The goal was to identify data that could lead to accurate cloud cover predictions and enhance mission planning effectiveness.

3.2.6.1 Data

Contacts were established with the National Oceanic and Atmospheric Administration (NOAA) and the NASA Marshall Space Flight Center. Briefings were provided by NOAA, both from their Special Projects Satellite Support group in Suitland, Maryland, and by their National Climatic Center in Asheville, North Carolina. The Air Force Environmental Technology Application Center (USAFETAC) in Asheville also provided this contractor with briefings and support data.

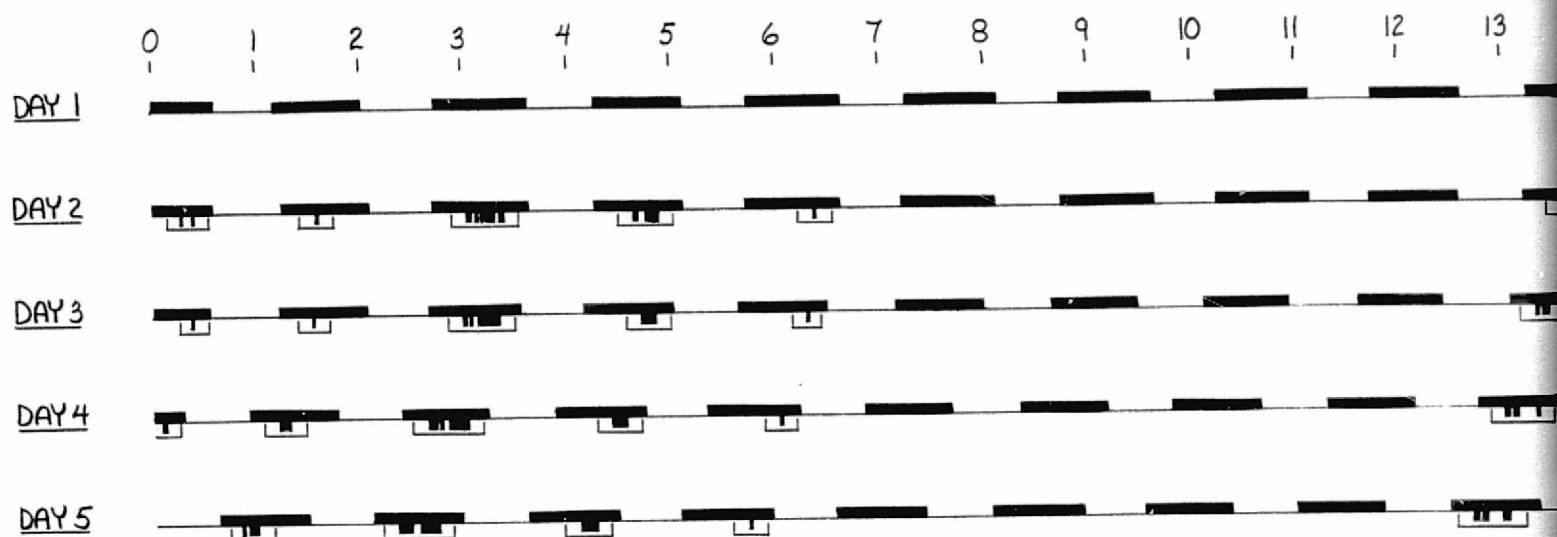
Our specific objectives were to collect published, world-wide climatological data (cloud cover) for inclusion in mission evaluation computer programs. The following data and source material, available from NOAA and USAFETAC, were identified:

1. Global Atlas of Relative Cloud Cover 1967-1970, U.S. Department of Commerce and United States Air Force. Based on data from meteorological satellites. Washington, D.C., September 1971.
2. Environmental Satellite Imagery, October 1977, NOAA, Environmental Data Service.
3. Guide to Standard Weather Summaries and Climatic Service, NWS, Asheville, January 1978.

(listing continued on Page 3-45)

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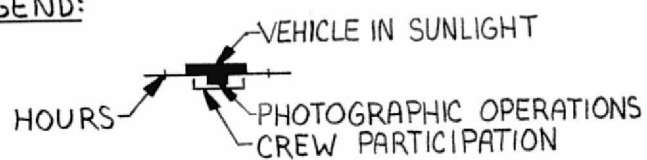
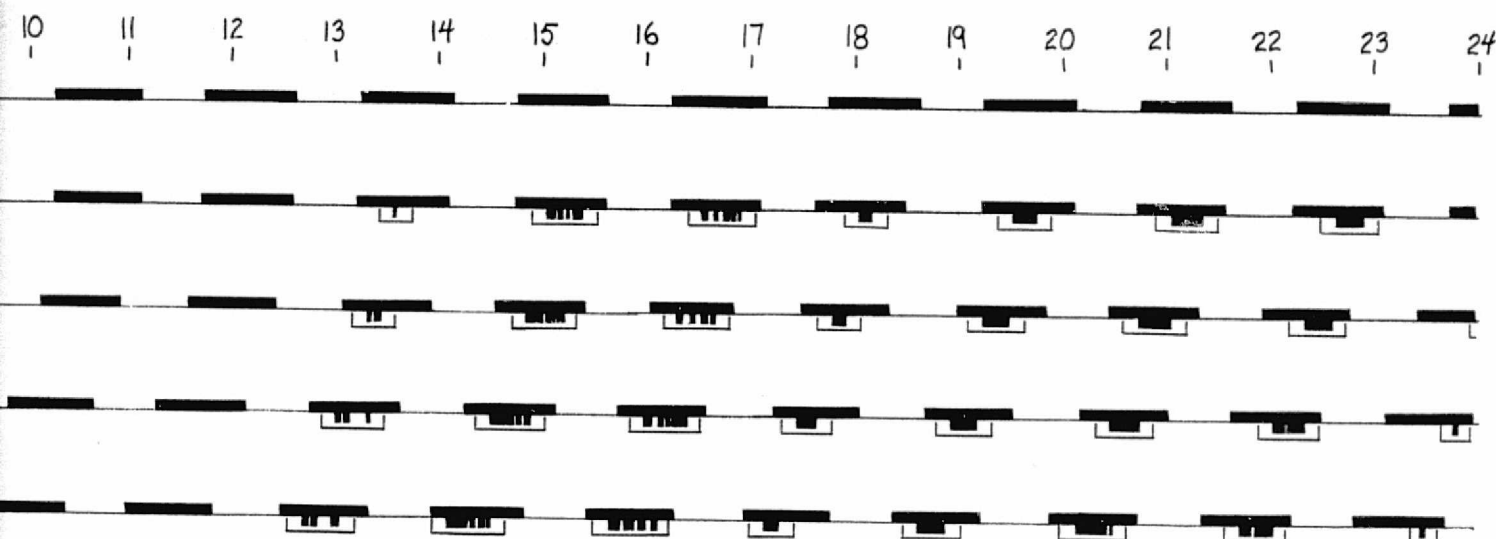


Figure 3-25 — STS-9 mission timelines

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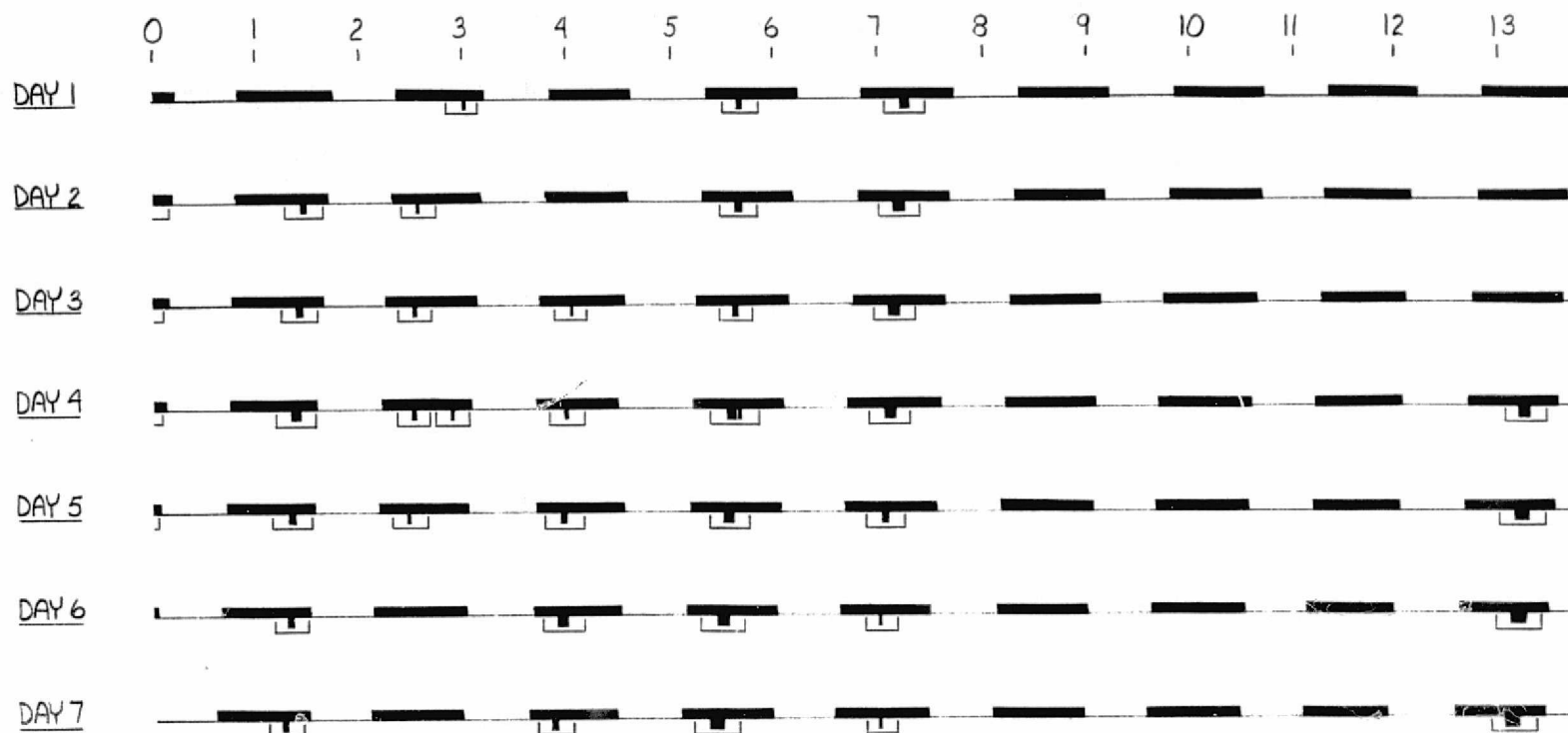


I=28.5°
H=274.1/227.7 KM
LAUNCH: 0900 HRS, 1 AUG.
MISSION: 5 DAYS

5 — STS-9 mission timelines - 5 days

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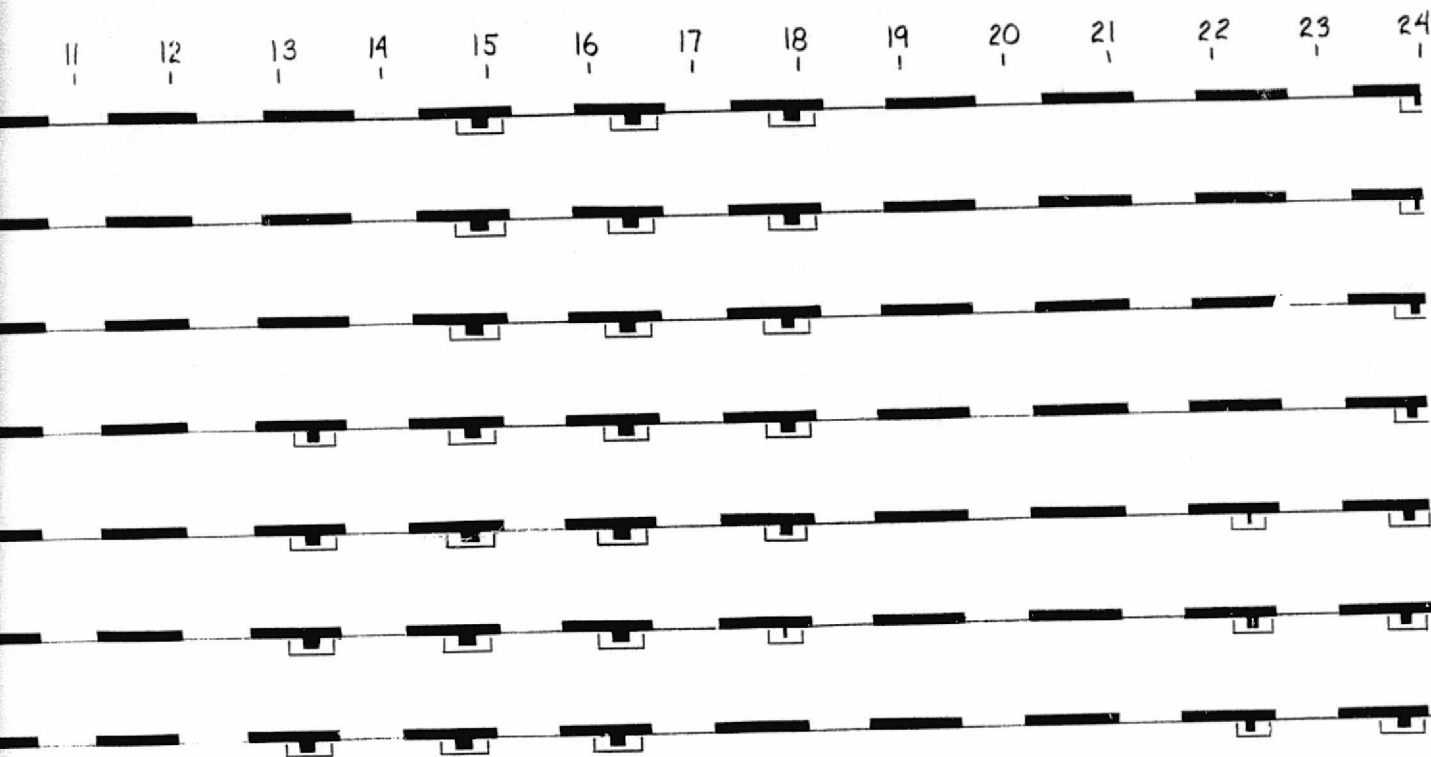
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Figure 3-26 — LFC mission timelines - 7 days, 57 d

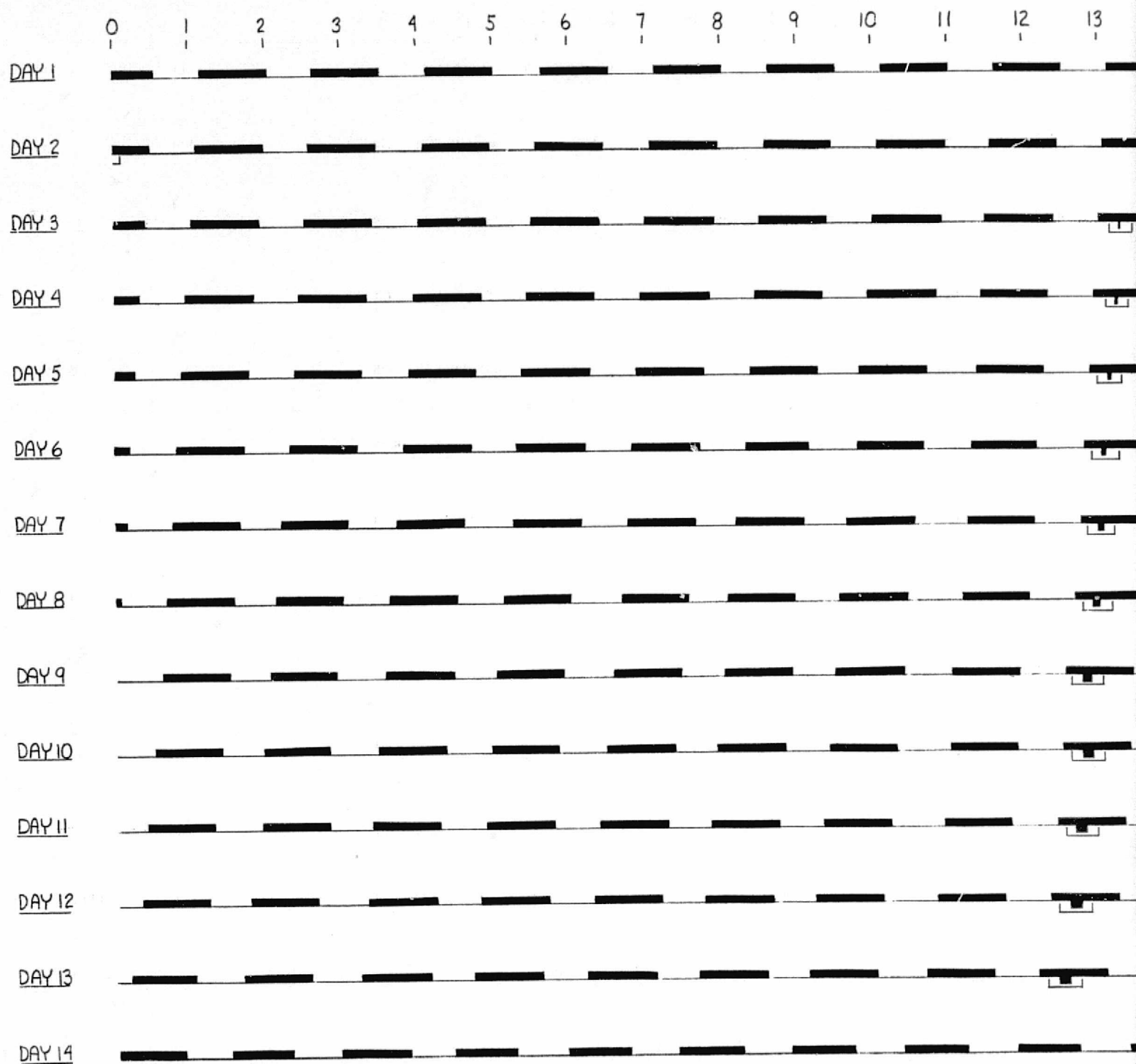
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WOLDOUT FRAME 2



I=57°
H=275.9 Km
LAUNCH:1500 HRS, 1 OCT
MISSION:7 DAYS

mission timelines - 7 days, 57 degrees inclination



LEGEND:

HOURS

VEHICLE IN SUNLIGHT

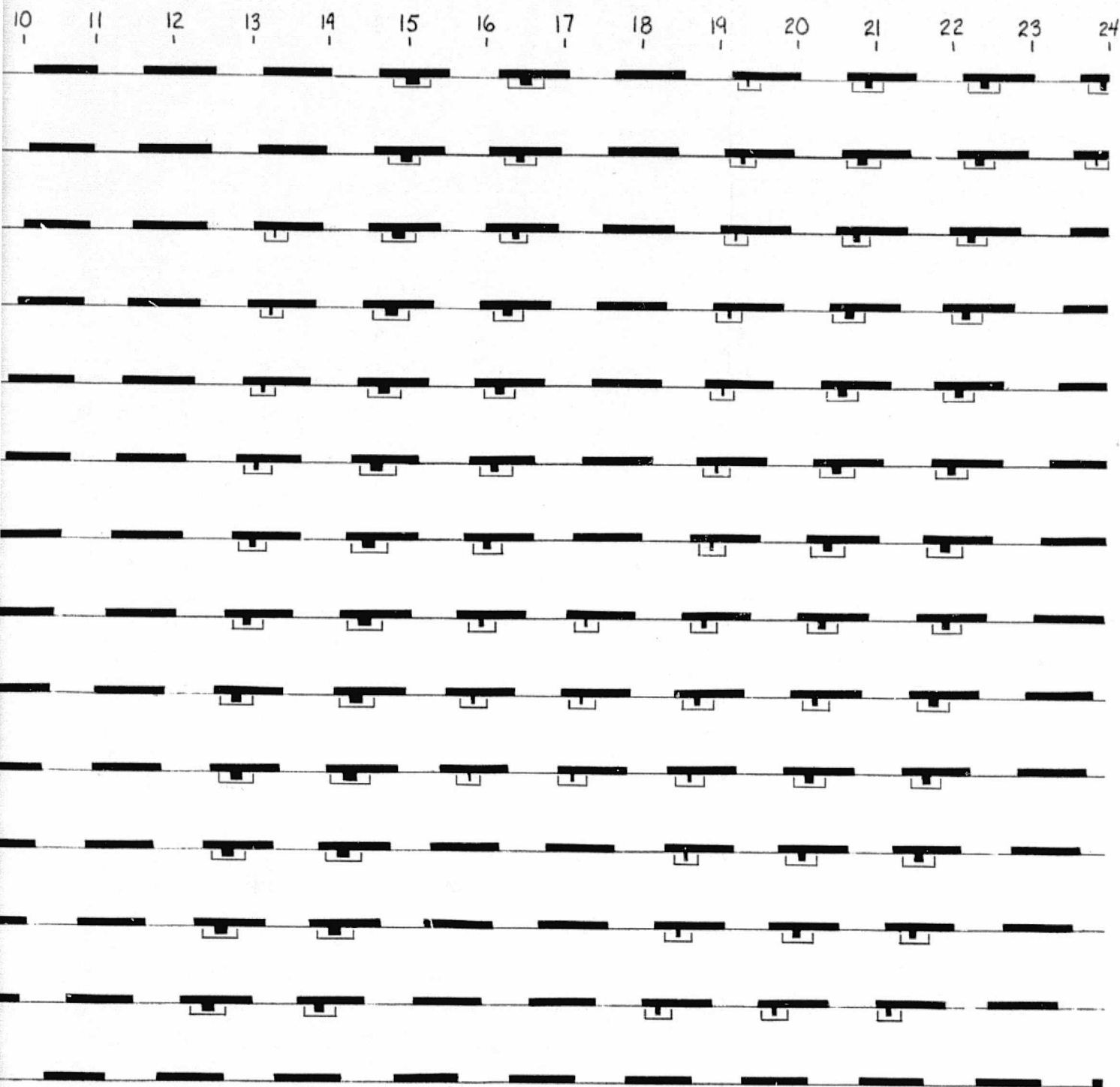
PHOTOGRAPHIC OPERATION

CREW PARTICIPATION

Figure 3-27 — LFC mission timelines - 14 days, 70 de

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I=70°
H=260 Km.
LAUNCH: 1300 HRS, 1 OCT
MISSION: 14 DAYS

ion timelines - 14 days, 70 degrees inclination

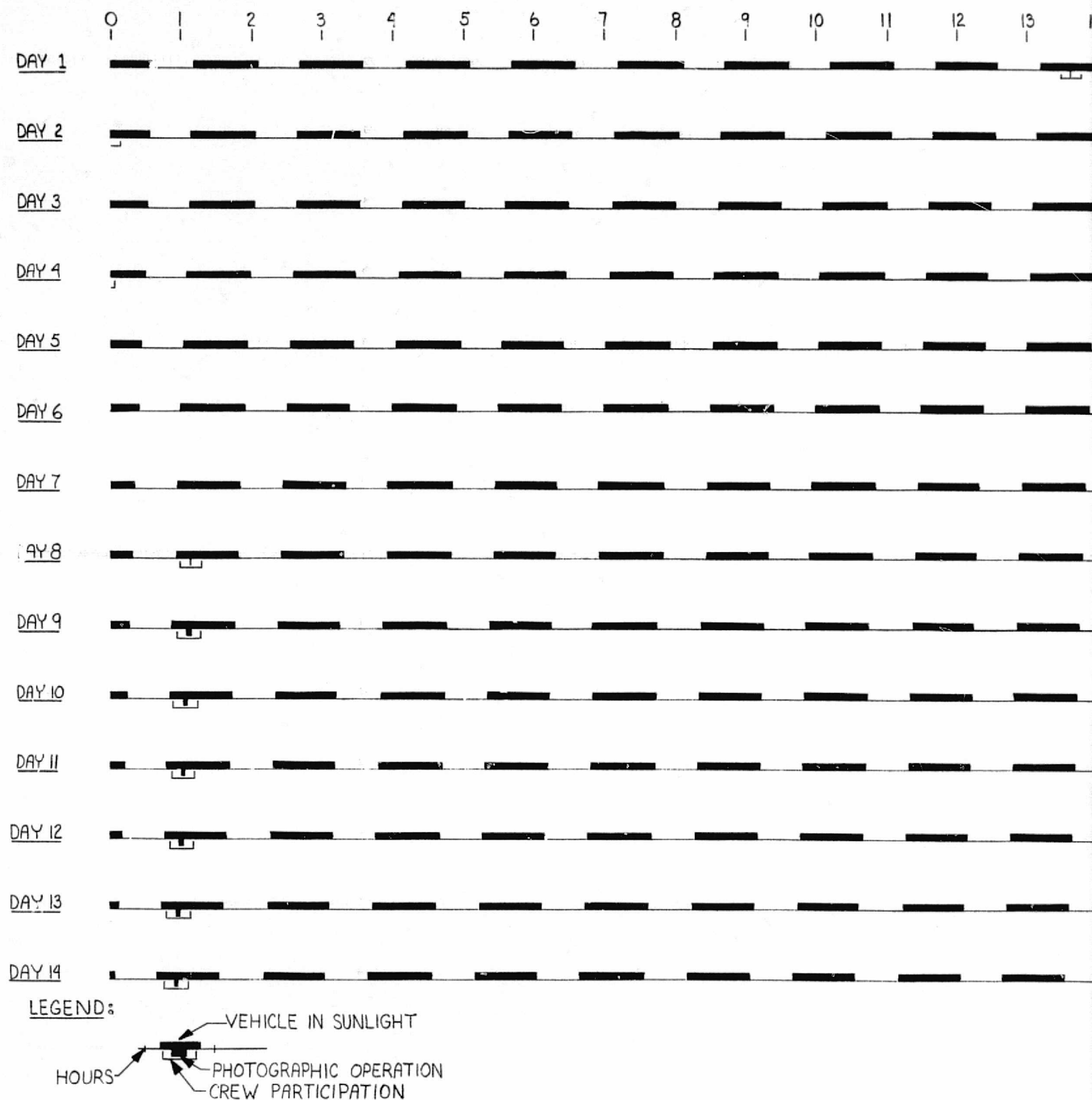
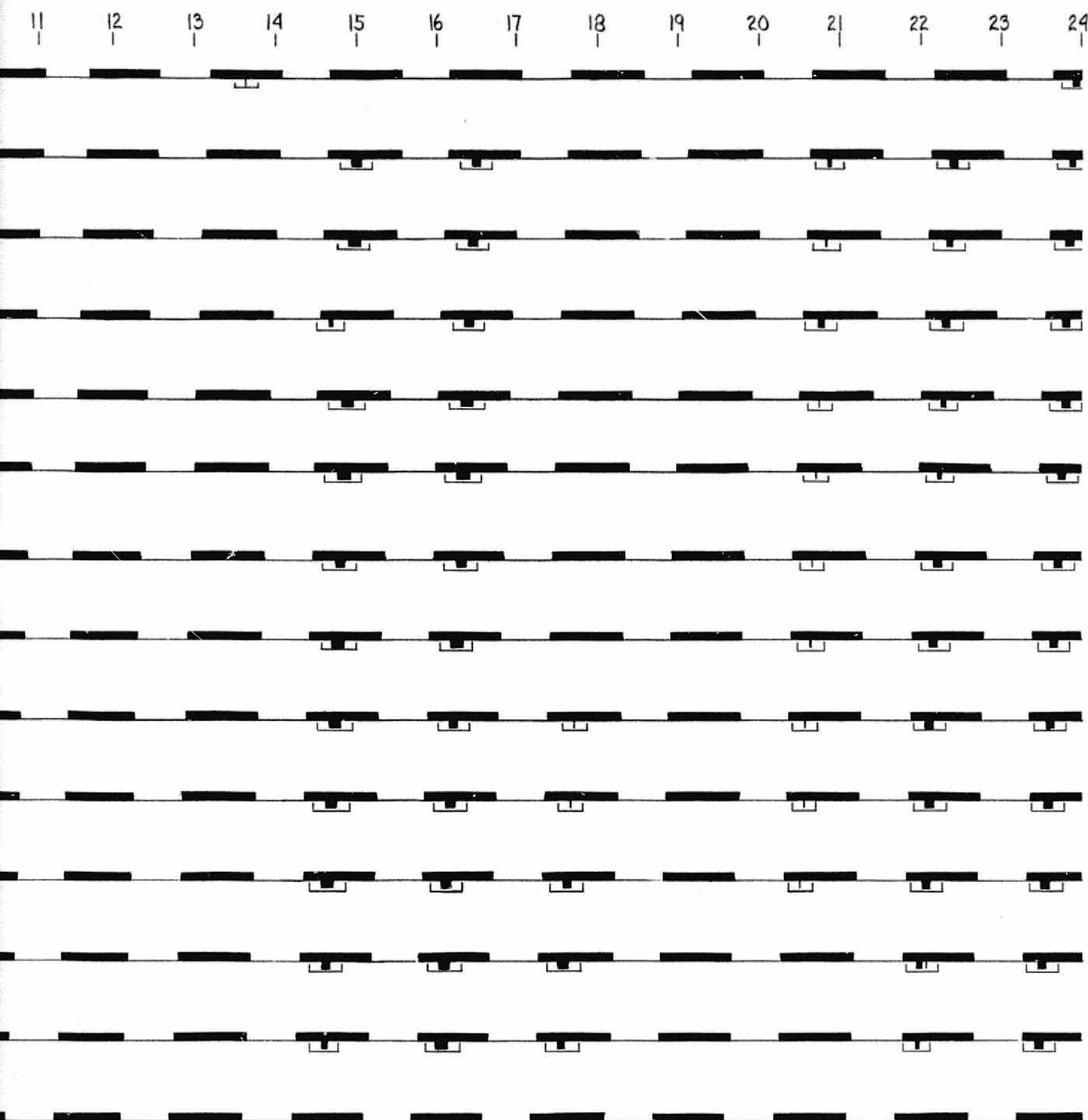


Figure 3-28 — LFC mission timelines - 14 days, 96.6 c



I=96.6°
H=273.7 Km
LAUNCH: 1100 HRS. 1 OCT
MISSION: 14 DAYS

4. USAF, Air Weather Services, "N" Summaries, R-F Summaries, Asheville, N. C.
5. "Statistical Study Relating Percentage Cloudiness as a Function of Mean Cloudiness", James Cox, Spaceflight Meteorology Group, NOAA.
6. Aerial Photographer's Clear Day Map - United States; U. S. Department of Commerce, ESSA, Environmental Data Service.
7. Climatic Atlas of the United States, NOAA, NCC, Asheville, N. C.
8. The 3DNEPH Data Base, USAFETAC, TN, 74-2.
9. Further Developments in Cloud Statistics for Computer Simulation; 1972, Marshall Space Flight Center, NASA CR-61389.
10. Studies in the Use of Cloud Type Statistics in Mission Simulation; 1974, Marshall Space Flight Center, NASA CR-129030.

Both the Air Force's 3DNEPH program and the Satellite Data Services Branch of NOAA can provide an immense amount of data from world-wide climatological observations made over a period of several years (e.g., cloud type, level, and coverage). The difficulty here is that the data must be summarized and built into a usable statistical base for time of year, time of day, and coordinates. It is relatively easy to acquire raw cloud/climatological data; the problem is to identify those data sources that have already produced the statistical base.

One source that does provide this information is Item 1 of the previous listing. Figs. 3-29 to 3-36 (from pages 182, 183, 194, 195, and 202 to 205) show world-wide relative cloud cover derived from radiometrically corrected satellite observations over the period 1967 to 1970. Each picture represents a spatial and temporal distribution of relative cloud cover for the period noted in the caption. In all pictures, the whitest areas represent the greatest degree of reflectance.

Each of the four kinds of charts have gray scale wedges with an overprinted number, or numbers. The numbers on the gray scales of the "mean octas" charts represent the mean occurrence of relative cloudiness, i.e., octas, over areas of the pictures containing matching gray scales. In the charts showing 0 to 2 octas, 3 to 6 octas, and 6 to 8 octas, the overprinted numbers on the gray scales represent the percentage frequency of occurrence of cloudiness in the range indicated. For example, on a 3 to 5 octas chart, the gray shade overprinted with a 40 is interpreted to mean that 3 to 6 octas of cloudiness occur 40 percent of the time in areas printed in this gray shade. Note that the gray scale step wedges on the 0 to 2 octas charts are the reverse of those on the 3 to 5 and 6 to 8 octas charts. This was done to highlight the cloudiest areas on all charts with the brightest gray shades. For a given square on the frequency-of-occurrence charts, the percentages shown on the three charts for each month, season, semiannual, or annual period will add up to 100 percent. Note that cloud cover is difficult to distinguish from desert area since reflectance values are presented here. The North Africa/Sahara area, from other data, is known to be more cloud-free than it appears here.

From these figures and other data of the Atlas, two key points emerge: (1) The August-October time window is likely the best for minimum cloud cover for the U. S. but not for the continents of importance to STS-9 coverage, and (2) The best time for these continents appears to be May as shown in Figs. 3-29 and 3-30 (pages 182 and 183). Thus, STS-9 long-range planning should take this into account and anticipate that a fairly considerable percentage of the desired photographic opportunities and/or full film utilization will not be achieved without a more opportunistic control of camera operations.

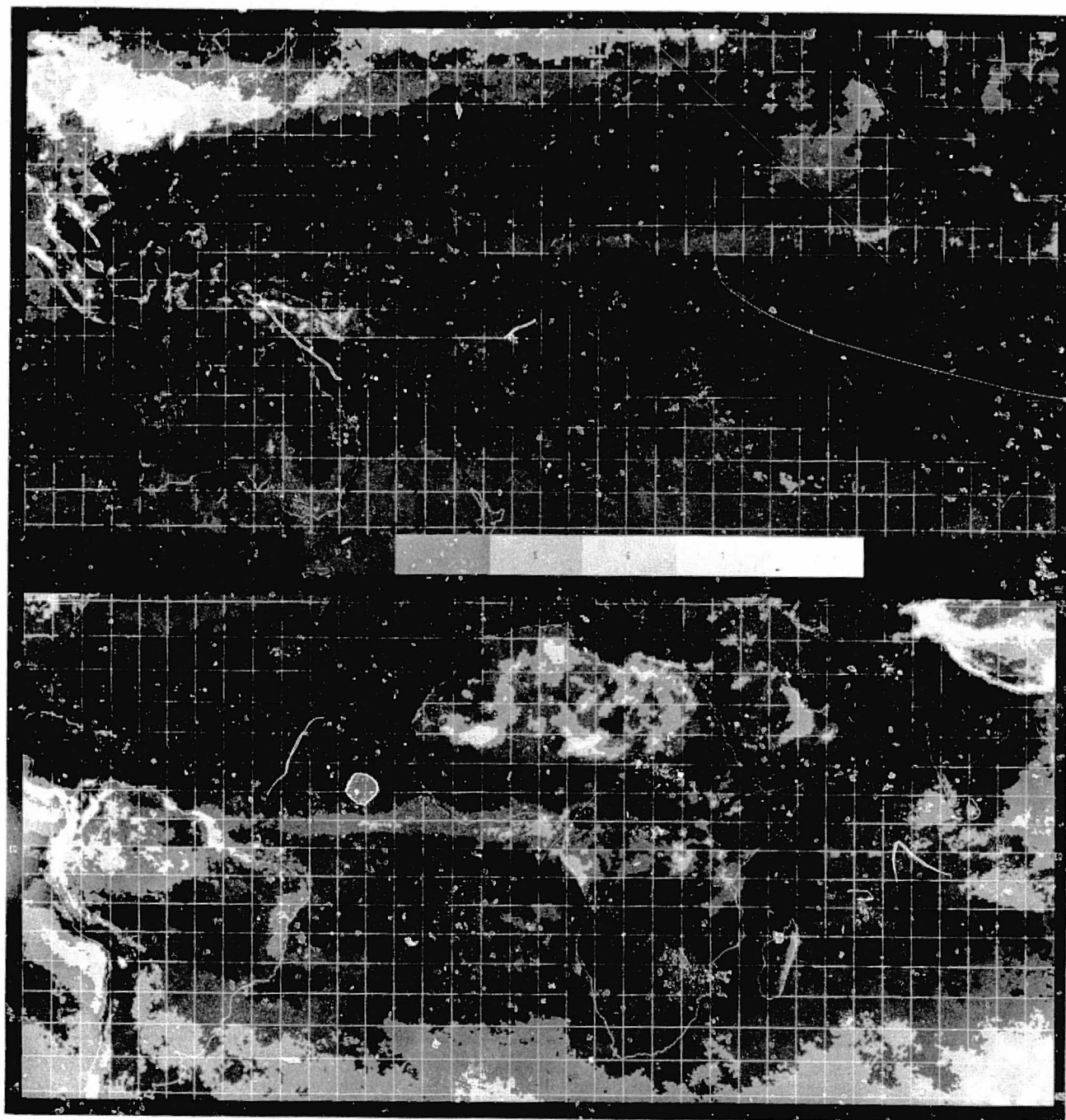


Figure 3-29 - Mercator satellite relative cloud cover, 1400 hours local time, 40°N to 40°S, mean octas, May 1967-1970

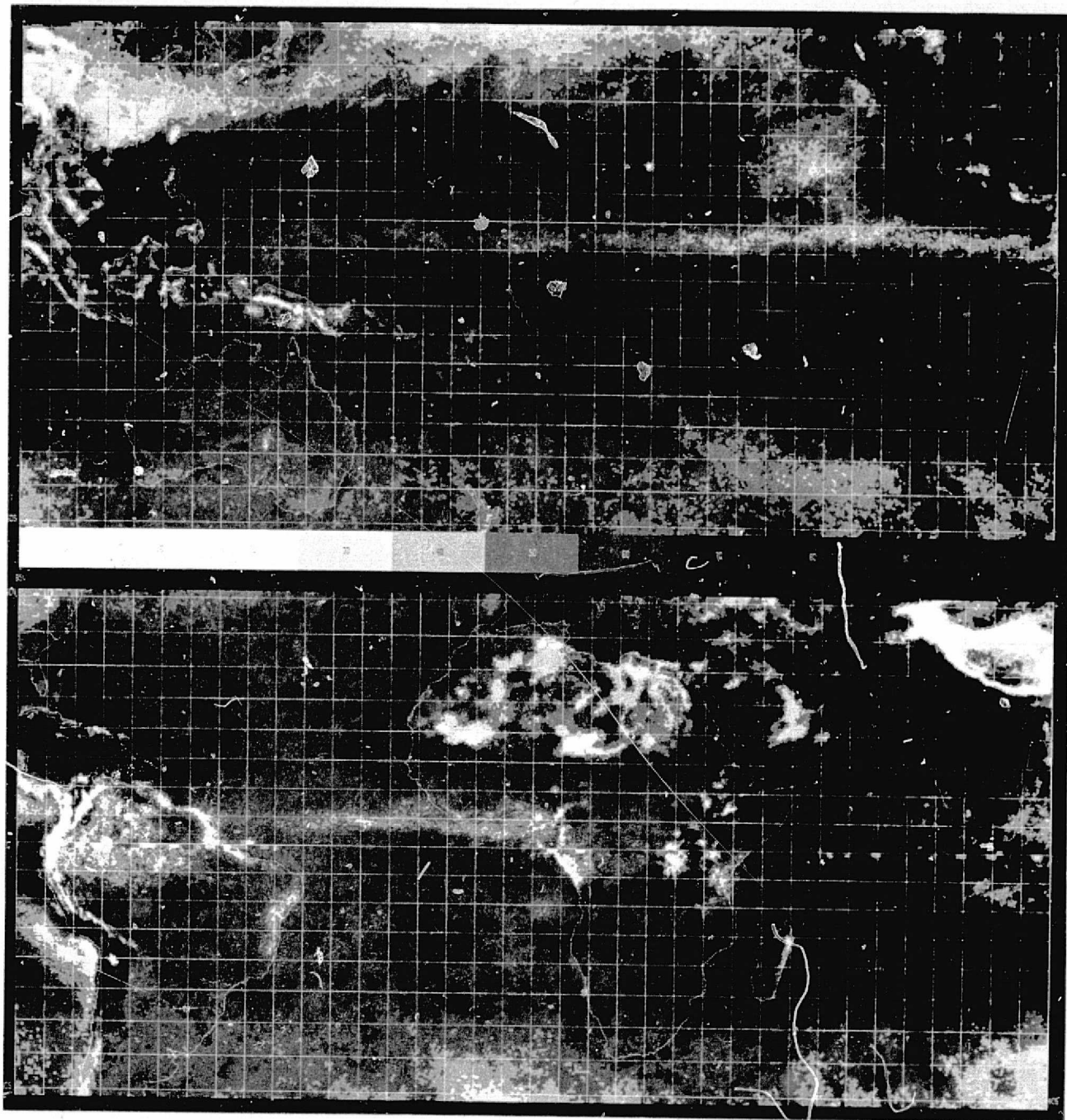


Figure 3-30 — Mercator satellite relative cloud cover, 1400 hours local time. 40°N to 40°S, 0-2 octas, May 1967-1970

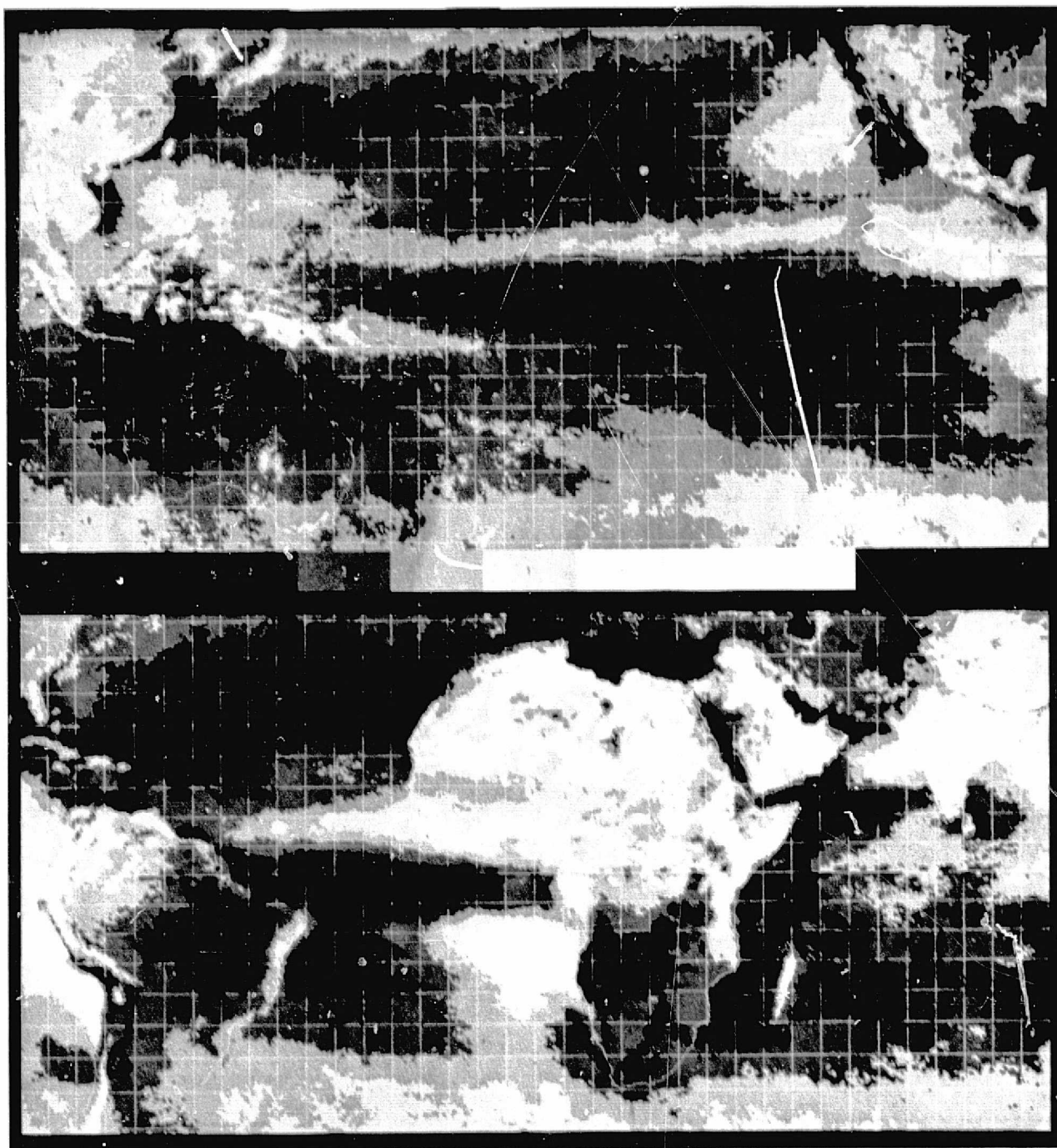


Figure 3-31 — Mercator satellite relative cloud cover, 1400 hours local time, 40°N to 40°S, mean octas, August 1967-1970

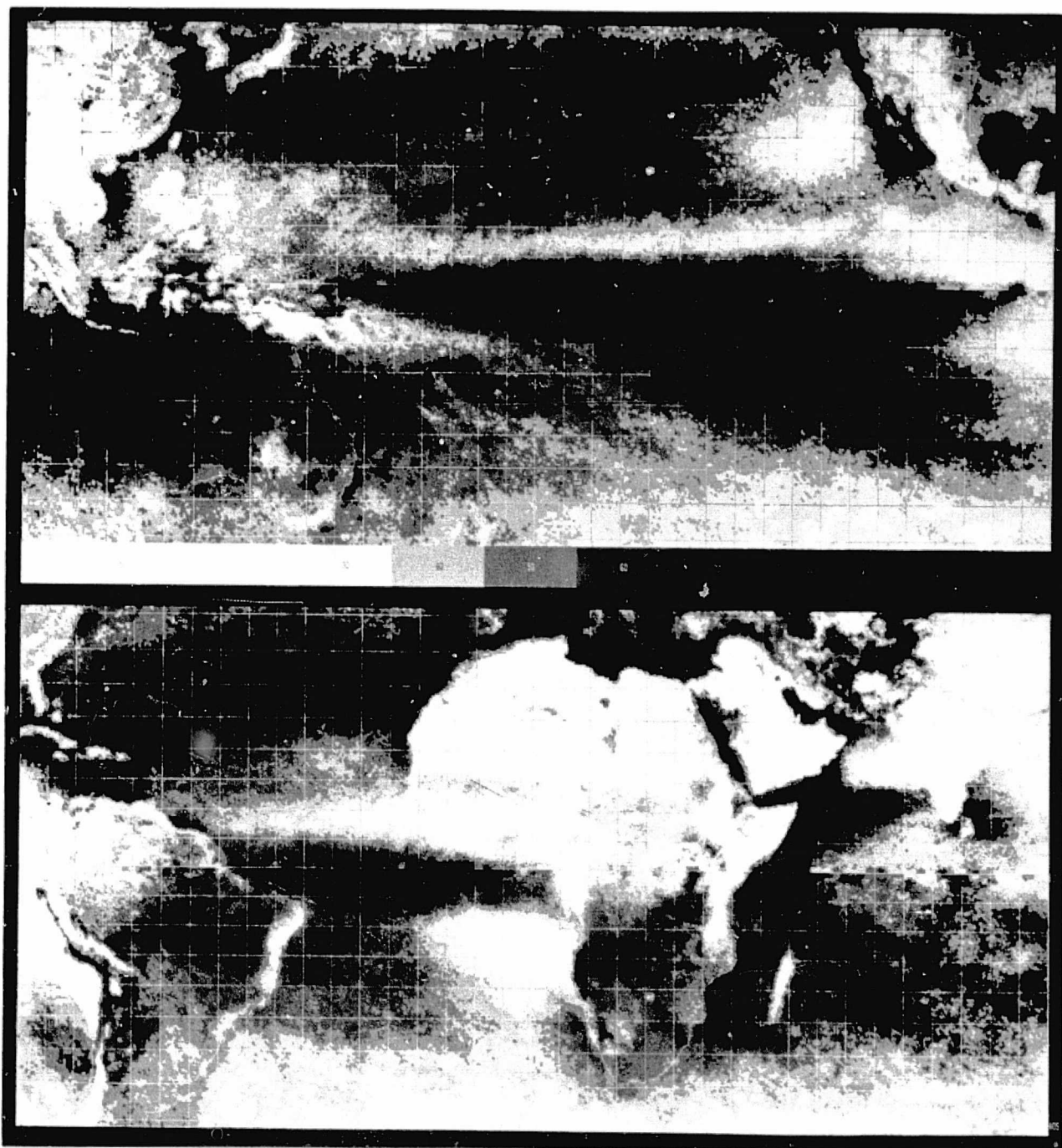


Figure 3-32 — Mercator satellite relative cloud cover, 1400 hours local time, 40°N to 40°S, 0-2 octas, August 1967-1970

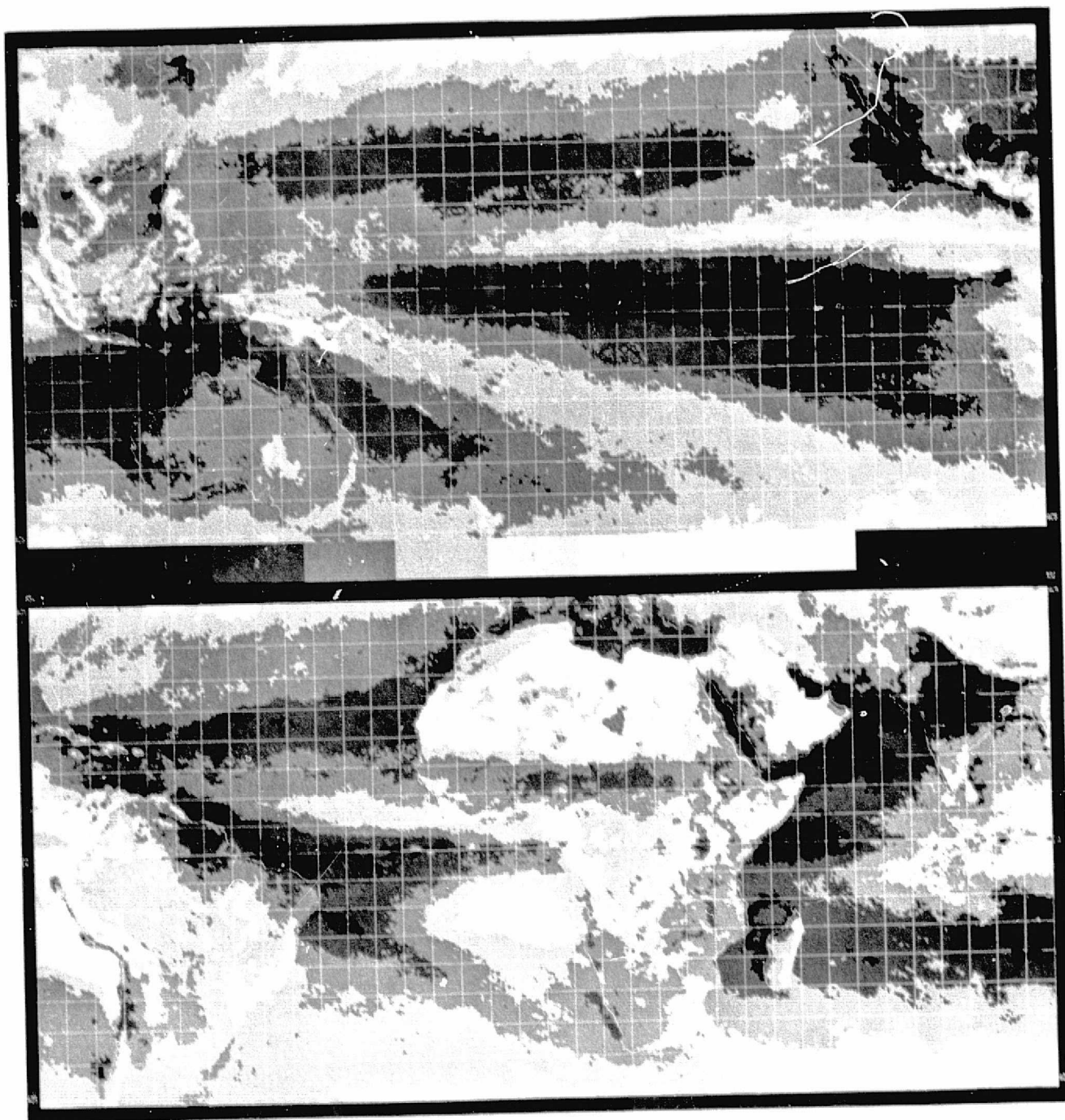


Figure 3-33 — Mercator satellite relative cloud cover, 1400 hours local time, 40°N to 40°S , mean octas, October 1967-1970

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Figure 3-34 — Mercator satellite relative cloud cover, 1400 hours local time, 40°N to 40°S, 0-2 octas, October 1967-1970

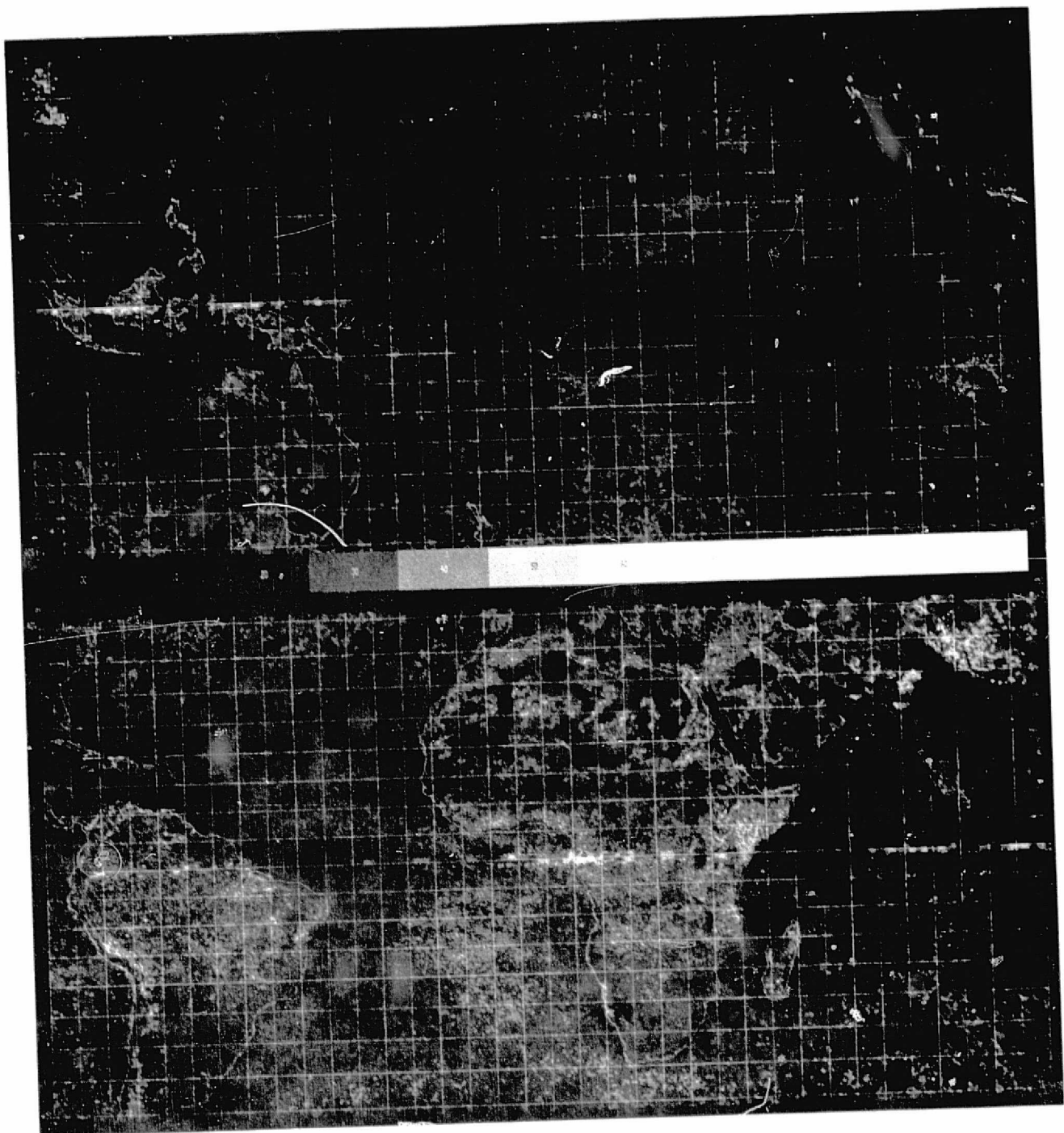


Figure 3-35 — Mercator satellite relative cloud cover, 1400 hours local time, 40°N to 40°S ,
3-5 octas, October 1967-1970

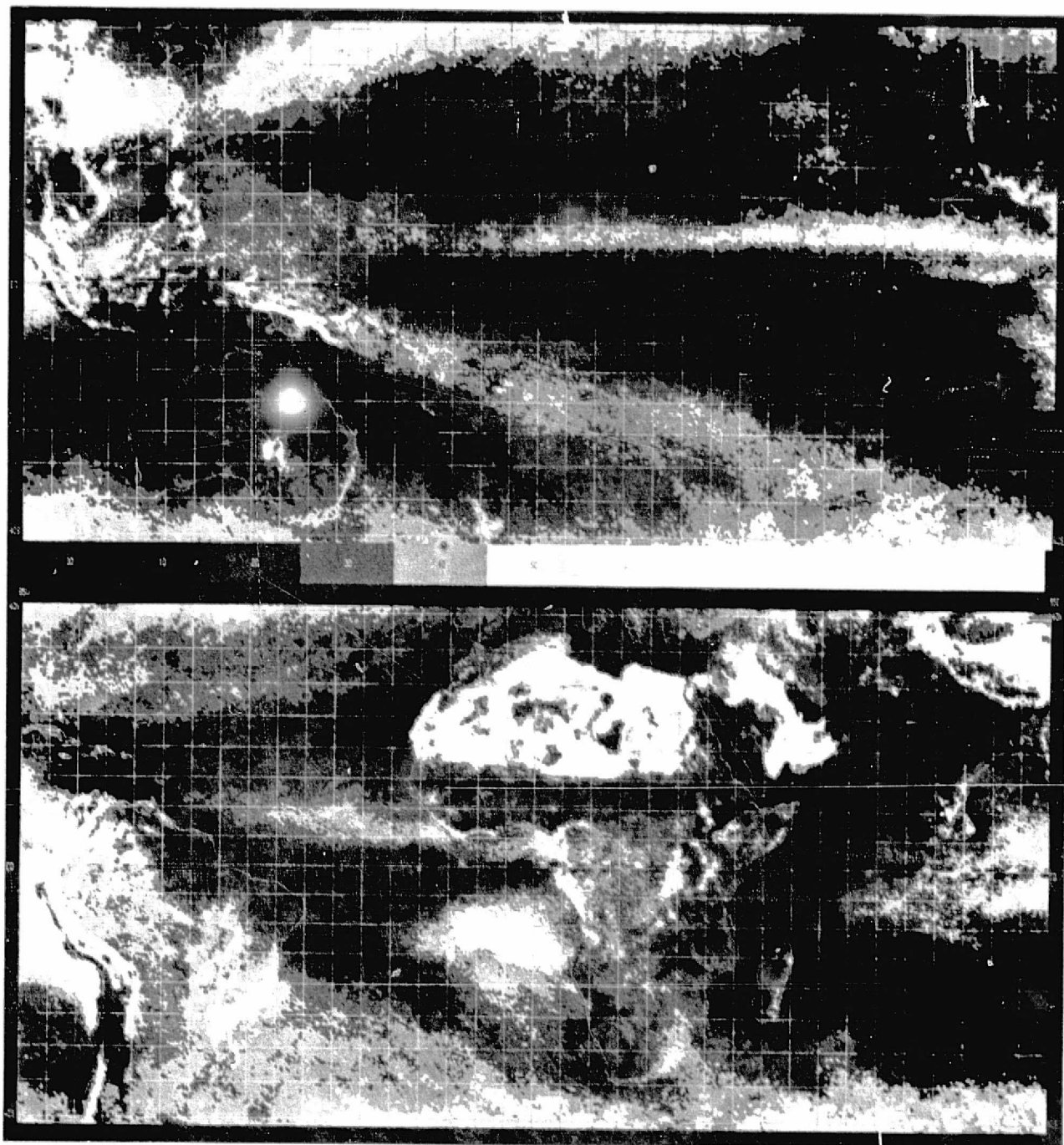


Figure 3-36 — Mercator satellite relative cloud cover, 1400 hours local time, 40°N to 40°S ,
6-8 octas, October 1967-1970

Figs. 3-37 and 3-38, taken from Items 6 and 7 of the previous listing respectively, show October and annual U. S. cloud cover. These support the earlier statement that the time period from July to October is near optimum for photographic opportunities over the U. S., with October the best on average across the country.

Therefore we see that later missions (after STS-9) whose principle photographic goal will be U. S. coverage are best planned as October missions. Complete acquisition will require longer times than shown in Section 3.2.5 due to some cloudiness.

Fig. 3-35 (from page 204 of Item 1) shows a phenomenon supported by the statistical research of Item 5. That is: Due to the nature of cloud formation and size, cloud coverage is reported in a large majority of cases as either total or clear (i. e., partly cloudy conditions are relatively scarce). We believe that the long range climatological statistics presented or referenced here can be relied upon, within reasonable limits, to provide data for anticipating photographic conditions.

However, the above data is incomplete. The diurnal, or time-of-day effect on cloud cover is another important variable. Typically, one finds increasing cloud cover during the day, especially in the tropics, and it could be critical to successful photographic coverage over a very limited mission duration. To address the question of optimum time of day for a minimum cloud condition, we first reviewed the USAFETAC 3DNEPH program and USAF "N" Summary data.

Neither data base is in a summarized statistical format; however, both offer cloud statistics, world-wide, as a function of time of day. During our working session at the National Climatic Center, "N" Summary data were gathered for 130 reporting stations world-wide. The stations are cataloged in Item 3 of the previous list and were selected on the basis of expected photographic coverage. This data could serve as the basis for a future update of existing cloud cover programs, as explained below.

In addition to the cloud cover data collected and presented above, the most important climatological data base with potential for advanced Shuttle mission planning was found in Items 9 and 10. This is a cloud cover model produced for the NASA Marshall Space Flight Center. It has been constructed to produce exactly the answers desired for advanced Orbiter/LFC mission planning. Given a desired latitude and longitude, time of year, and times of day, this program will produce as output:

"The number of passes over a target required to produce, with a given percentage of confidence, a given percentage of the target area".

It has within its data base the probability of cloud cover at three hourly intervals for five categories of cloud cover, for each month of the year, in over 30 distinct climatological regions world-wide. This program can produce statistically-based weather predictions on a global basis. The technical monitor for this cloud cover program indicated that the data base is still considered adequate, although it has not been accessed for several years. The "N" Summary data we have acquired could be utilized to update the program data base.

This program, although not presently in operation, belongs to a group at MSPC that is currently performing weather studies for JSC for Shuttle takeoff and landing times.

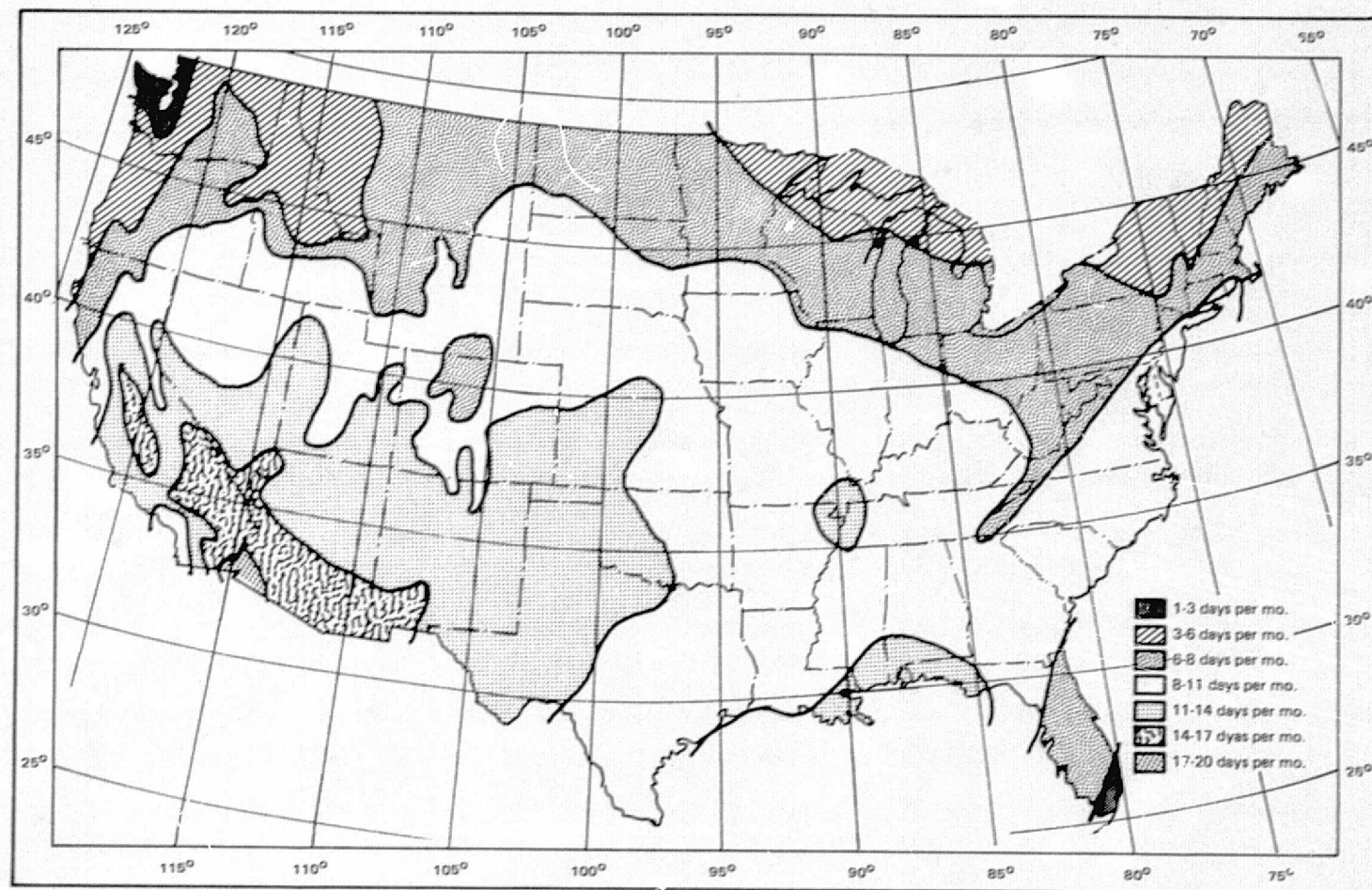


Figure 3-37 - Map based on "Aerial Photographer's Clear Day Map - October"
from U. S. Department of Commerce

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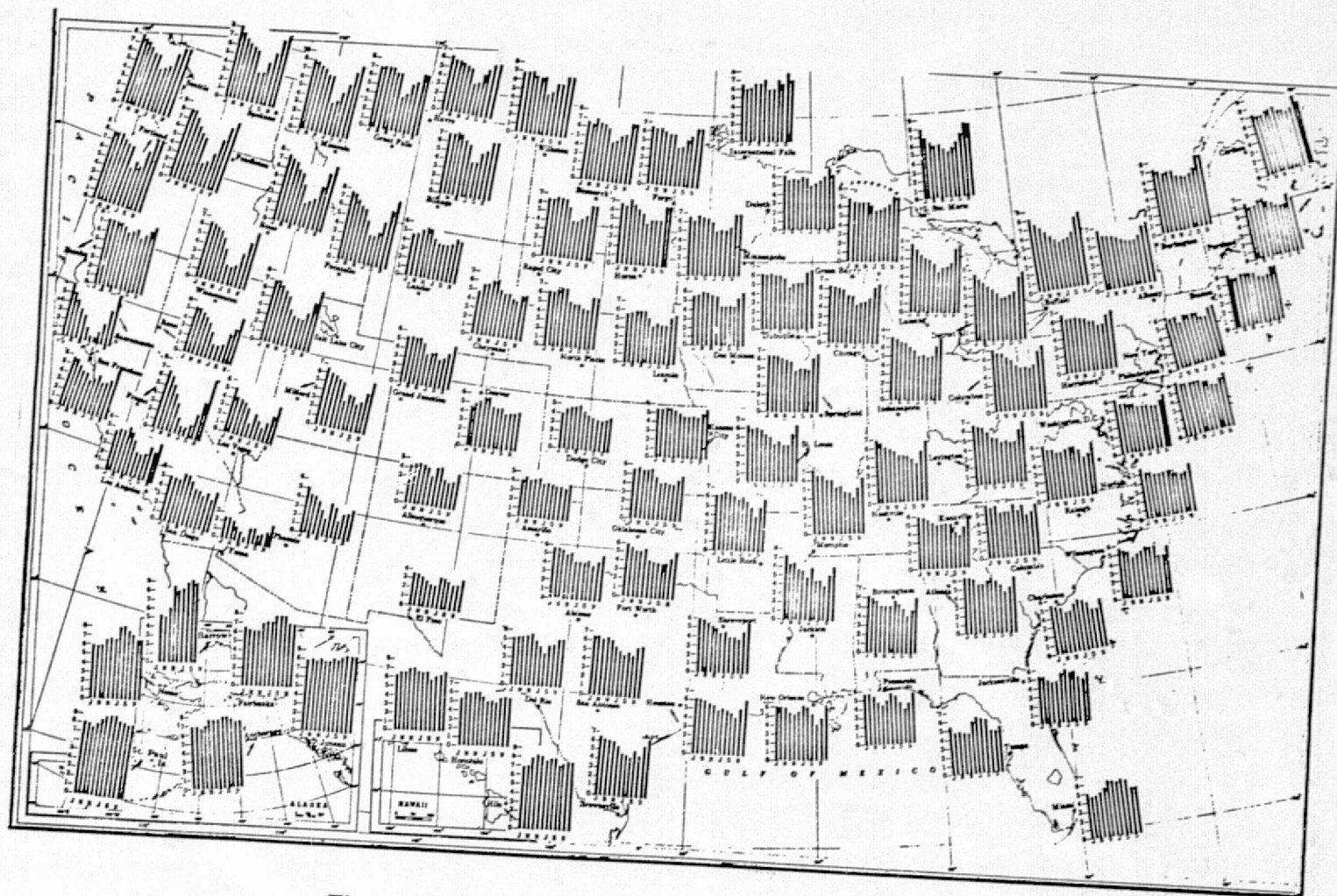


Figure 3-38 — Mean monthly sky cover, sunrise to sunset

4. CONCLUSIONS AND RECOMMENDATIONS

On the basis of the work done in this study program, we draw the following conclusions and associated recommendations.

- The "current design status" of the LFC can readily be modified to meet additional requirements and to be deployable in the Orbiter, on a free-flyer, and in the WB-57F.
- Interface requirements for LFC deployment in the Orbiter are reasonable but the thermal effects of other experiments near the LFC are, as yet, unassessable. Ongoing investigation in this area is expected.
- These investigations have demonstrated that the efficient use of the LFC requires careful control of many conditions.
- The basic software tools and reference data are available to enable the evaluation of the proposed LFC missions and to develop specific parameters and sequences for scheduled missions to achieve maximum possible efficiency.

It is recommended, therefore, that an ongoing activity be established to bring all of the available tools together and to become prepared to effectively support the planning effort required to maximize the results of LFC utilization.

Appendix A

OPTIMUM ORBIT ALTITUDES

Table A-1 — Optimum Orbit Altitudes, Inclination 28.5 degrees, Altitude Range 185 to 600 Kilometers
(Sheet 1 of 4)

Orbit Incl. (Deg.)	Useful ^① Altitudes (Km)	Footprint Width ^② (Deg.)	Gnd. Track Spacing (Deg.)	Effic. $GTS \div FW$ —	Revs. To Close (#)	Time To Close (Days)	* Effic. $\geq .75$
28.5	205.8	2.9	1.5	.52	239	14.7	
	207.0	2.9	1.6	.55	223	13.7	
	208.7	2.9	1.7	.59	191	11.7	
	212.8	3.0	2.0	.67	175	10.8	
	215.4	3.0	2.3	.77	159	9.8	*
	218.5	3.1	2.5	.81	143	8.8	*
	222.6	3.1	2.8	.90	127	7.8	*
	225.2	3.2	1.5	.47	238	14.7	
	231.1	3.3	1.7	.52	206	12.7	
	239.3	3.4	2.1	.62	174	10.8	
	248.9	3.5	1.6	.46	221	13.7	
	251.1	3.6	2.5	.69	142	8.8	
	253.7	3.6	1.7	.47	205	12.7	
	264.3	3.7	1.5	.40	236	14.7	
	266.1	3.8	2.1	.55	173	10.8	
	269.8	3.8	3.3	.87	110	6.9	*
	274.1	3.9	2.3	.59	157	9.8	
	276.5	3.9	1.8	.46	204	12.7	
	291.1	4.1	1.6	.39	219	13.7	
	296.5	4.2	2.9	.69	125	7.8	
	299.3	4.2	1.8	.43	203	12.7	
	308.9	4.4	1.9	.43	187	11.8	
	312.4	4.4	3.3	.75	109	6.9	*
	315.2	4.5	1.4	.31	249	15.7	
	317.2	4.5	2.5	.56	140	8.8	
	320.4	4.5	2.1	.47	171	10.8	
	322.4	4.6	1.8	.39	202	12.7	
	323.9	4.6	1.5	.33	233	14.7	
	344.1	4.9	1.5	.31	232	14.7	

① Provides uniformly spaced ground tracks along Equator with spacing $\leq$ footprint width.
② Along Equator.

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Table A-1 - Optimum Orbit Altitudes, Inclination 28.5 degrees, Altitude Range 185 to 600 Kilometers
(Sheet 2 of 4)

Orbit Incl. (Deg.)	Useful ^① Altitudes (Kms)	Footprint Width ^② (Deg.)	Gnd. Track Spacing (Deg.)	Effic. $GT \div FW$ —	Revs. To Close (#)	Time To Close (Days)	
28.5	345.7	4.9	1.8	.37	201	12.7	
	347.8	4.9	2.1	.43	170	10.8	
	350.9	5.0	2.6	.52	139	8.8	
	353.0	5.0	1.4	.28	247	15.7	
	355.7	5.0	3.3	.66	108	6.9	
	359.5	5.1	1.9	.37	185	11.8	
	364.5	5.2	4.7	.90	77	4.9	*
	369.1	5.2	1.8	.35	200	12.7	
	372.0	5.3	2.9	.55	123	7.8	
	375.6	5.3	2.1	.40	169	10.8	
	377.6	5.3	1.7	.32	215	13.7	
	391.3	5.5	1.5	.27	245	15.7	
	392.8	5.6	1.8	.32	199	12.8	
	395.2	5.6	2.3	.41	153	9.8	
	399.6	5.6	3.3	.59	107	6.9	
	403.5	5.7	2.1	.37	168	10.8	
	405.6	5.7	1.5	.26	229	14.7	
	416.7	5.9	1.8	.31	198	12.8	
	419.3	5.9	2.6	.44	137	8.8	
	421.9	6.0	1.7	.28	213	13.7	
	426.3	6.0	4.7	.78	76	4.9	*
	430.0	6.1	1.4	.23	243	15.7	
	431.9	6.1	2.1	.34	167	10.8	
	436.7	6.2	3.9	.63	91	5.9	
	444.1	6.3	3.4	.54	106	6.9	
	447.0	6.3	1.6	.25	227	14.7	
	449.8	6.4	3.0	.47	121	7.9	
	454.1	6.4	2.6	.41	136	8.8	
	457.6	6.5	2.4	.37	151	9.8	
^① Provides uniformly spaced ground tracks along Equator with spacing $\leq$ footprint width. ^② Along Equator.							

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Table A-1 — Optimum Orbit Altitudes, Inclination 28.5 degrees, Altitude Range 185 to 600 Kilometers
(Sheet 3 of 4)

Orbit Incl. (Deg.)	Useful ^① Altitudes (Kilometers)	Footprint Width ^② (Deg.)	Ground Track Spacing (Deg.)	Effic. GTS ÷ FW —	Revs. To Close (#)	Time To Close (Days)	
28.5	460.4	6.5	2.2	.34	166	10.8	
	462.8	6.5	2.0	.31	181	11.8	
	464.8	6.6	1.8	.27	196	12.8	
	466.7	6.6	1.7	.26	211	13.7	
	468.2	6.6	1.6	.24	226	14.7	
	469.5	6.6	1.5	.23	241	15.7	
	509.3	7.2	1.5	.21	239	15.7	
	510.6	7.2	1.6	.22	224	14.7	
	512.0	7.2	1.7	.24	209	13.7	
	513.9	7.3	1.9	.26	194	12.8	
	515.9	7.3	2.0	.27	179	11.8	
	518.3	7.3	2.2	.30	164	10.8	
	521.3	7.4	2.4	.32	149	9.8	
	524.6	7.4	2.7	.36	134	8.8	
	529.3	7.5	3.0	.40	119	7.9	
	532.0	7.5	1.6	.21	223	14.7	
	535.2	7.6	3.5	.46	104	6.9	
	538.7	7.6	1.9	.25	193	12.8	
	542.8	7.7	4.0	.52	89	5.9	
	547.8	7.7	2.2	.29	163	10.8	
	549.6	7.8	1.5	.19	237	15.7	
	553.7	7.8	4.9	.63	74	4.9	
	558.3	7.9	1.7	.22	207	13.8	
	560.9	7.9	2.7	.34	133	8.8	
	563.7	8.0	1.9	.24	192	12.8	
	570.0	8.1	6.1	.75	59	3.9	*
	575.6	8.1	1.6	.20	221	14.7	
	577.4	8.2	2.2	.27	162	10.8	
	581.7	8.2	3.5	.43	103	6.9	

① Provides uniformly spaced ground tracks along Equator with spacing $\leq$ footprint width.

② Along Equator.

Table A-1 - Optimum Orbit Altitudes, Inclination 28.5 degrees, Altitude Range 185 to 600 Kilometers
(Sheet 4 of 4)

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Table A-2 - Optimum Orbit Altitudes, Inclination 57.0 Degrees, Altitude Range 185 to 600 Kilometers
(Sheet 1 of 3)

Orbit Incl. (Deg.)	Useful Altitudes (Km)	Footprint Width (Deg.)	Gnd. Track Spacing (Deg.)	Effic. GTS ÷ FW —	Revs. To Close (#)	Time To Close (Days)	* Effic. 2.75
57	203.5	1.6	1.6	1.00	225	13.8	*
	205.0	1.6	1.5	.94	241	14.8	*
	243.0	2.0	1.5	.75	239	14.8	*
	244.1	2.0	1.6	.80	223	13.8	*
	245.8	2.0	1.7	.85	207	12.8	*
	247.6	2.0	1.9	.95	191	11.8	*
	261.9	2.1	1.5	.71	238	14.8	
	267.8	2.2	1.7	.77	206	12.8	*
	275.9	2.2	2.0	.91	174	10.9	*
	285.2	2.3	1.6	.70	221	13.8	
	290.0	2.3	1.7	.74	205	13.1	
	300.6	2.4	1.5	.63	236	14.8	
	302.2	2.4	2.1	.88	173	10.9	*
	310.2	2.5	2.3	.92	157	9.9	*
	312.4	2.5	1.7	.68	204	12.8	
	327.0	2.6	1.6	.62	219	13.8	
	328.9	2.6	2.1	.81	172	10.9	*
	335.0	2.7	1.7	.63	203	12.8	
	344.5	2.8	1.9	.68	187	11.9	
	350.7	2.8	1.4	.50	249	15.8	
	352.8	2.8	2.6	.93	140	8.9	*
	355.7	2.9	2.1	.72	171	10.9	
	357.8	2.9	1.7	.59	202	12.8	
	359.5	2.9	1.5	.52	233	14.8	
	379.3	3.1	1.5	.48	232	14.8	
	380.7	3.1	1.8	.58	201	12.8	
	382.8	3.1	2.1	.68	170	10.9	
	385.9	3.1	2.6	.84	139	8.9	*
	388.0	3.1	1.4	.45	247	15.8	

① Provides uniformly spaced ground tracks along Equator with spacing $\leq$ footprint width.
② Along Equator.

Table A-2 - Optimum Orbit Altitudes, Inclination 57.0 Degrees, Altitude Range 185 to 600 Kilometers
(Sheet 2 of 3)

Orbit Incl. (Deg.)	Useful ^① Altitudes (Kmr)	Footprint Width ^② (Deg.)	Grnd. Track Spacing (Deg.)	Effic. GTS± FW —	Revs. To Close (#)	Time To Close (Days)	
57	394.3	3.2	1.9	.59	185	11.9	
	403.9	3.2	1.8	.56	200	12.8	
	406.9	3.3	2.9	.88	123	7.9	*
	410.4	3.3	2.1	.64	169	10.9	
	412.2	3.3	1.7	.52	215	13.8	
	425.7	3.4	1.5	.44	245	15.8	
	427.2	3.4	1.8	.53	199	12.8	
	429.6	3.5	2.3	.66	153	9.9	
	433.9	3.5	3.3	.94	107	6.9	*
	438.0	3.5	2.1	.60	168	10.9	
	439.8	3.5	1.6	.46	229	14.8	
	450.7	3.6	1.8	.50	198	12.9	
	453.3	3.6	2.6	.72	137	8.9	
	455.9	3.7	1.7	.46	213	13.8	
	464.1	3.7	1.5	.41	243	15.8	
	465.9	3.7	2.1	.57	167	10.9	
	474.4	3.8	1.8	.47	197	12.9	
	478.0	3.8	3.4	.89	106	6.9	*
	480.9	3.9	1.5	.38	227	14.8	
	483.5	3.9	3.0	.77	121	7.9	*
	487.8	3.9	2.6	.67	136	8.9	
	491.3	4.0	2.4	.60	151	9.9	
	494.1	4.0	2.2	.55	166	10.8	
	496.5	4.0	2.0	.50	181	11.9	
	498.5	4.0	1.8	.45	196	12.9	
	500.2	4.0	1.7	.43	211	13.8	
	501.7	4.0	1.6	.40	226	14.8	
	503.0	4.0	1.5	.38	241	15.8	
	542.2	4.4	1.5	.34	239	15.8	
^① Provides uniformly spaced ground tracks along Equator with spacing $\leq$ footprint width. ^② Along Equator.							

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Table A-2 - Optimum Orbit Altitudes, Inclination 57.0 Degrees, Altitude Range 185 to 600 Kilometers
(Sheet 3 of 3)

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Table A-3 - Optimum Orbit Altitudes, Inclination 70.0 Degrees, Altitude Range 185 to 600 Kilometers
(Sheet 1 of 3)

Orbit Incl. (Deg.)	Useful ^① Altitudes (Kms)	Footprint Width ^② (Deg.)	Gnd. Track Spacing (Deg.)	Effic. $GTS \div FW$ —	Revs. To Close (#)	Time To Close (Days)	* Effic. $\geq .75$
70	225.9	1.6	1.6	1.00	225	13.9	*
	227.4	1.6	1.5	.94	241	14.9	*
	264.8	1.9	1.5	.79	239	14.9	*
	266.1	1.9	1.6	.84	223	13.9	*
	267.6	1.9	1.7	.89	207	12.9	*
	269.6	1.9	1.9	1.00	191	11.9	*
	283.7	2.0	1.5	.75	238	14.9	*
	289.6	2.1	1.7	.81	206	12.9	*
	297.6	2.1	2.1	1.00	174	10.9	*
	306.9	2.2	1.6	.73	221	13.9	
	311.7	2.2	1.8	.82	205	12.9	*
	322.0	2.3	1.5	.65	236	14.9	
	323.7	2.3	2.1	.91	173	10.9	*
	331.7	2.4	2.3	.96	157	9.9	*
	333.9	2.4	1.8	.75	204	12.9	*
	348.3	2.5	1.6	.64	219	13.9	
	350.2	2.5	2.1	.84	172	10.9	*
	356.3	2.6	1.8	.69	203	12.9	
	365.7	2.6	1.9	.73	187	11.9	
	371.9	2.7	1.4	.52	249	15.9	
	373.9	2.7	2.6	.96	140	8.9	*
	376.9	2.7	2.1	.78	171	10.9	*
	378.9	2.7	1.8	.67	202	12.9	
	380.4	2.7	1.5	.56	233	14.9	
	401.7	2.9	1.8	.62	201	12.9	
	403.7	2.9	2.1	.72	170	10.9	
	406.7	2.9	2.6	.90	139	8.9	*
	408.9	2.9	1.4	.48	247	15.9	
	415.0	3.0	1.9	.63	185	11.9	

① Provides uniformly spaced ground tracks along Equator with spacing $\leq$ footprint width.
② Along Equator.

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Table A-3 — Optimum Orbit Altitudes, Inclination 70.0 Degrees, Altitude Range 185 to 600 Kilometers
(Sheet 2 of 3)

Orbit Incl. (Deg.)	Useful ^① Altitudes (Kms)	Footprint Width ^② (Deg.)	Gnd. Track Spacing (Deg.)	Effic. GTS ÷ FW —	Revs. To Close (#)	Time To Close (Days)	
70	424.6	3.0	1.8	.60	200	12.9	
	427.6	3.1	2.9	.94	123	7.9	*
	430.9	3.1	2.1	.68	169	10.9	
	433.0	3.1	1.7	.55	215	13.9	
	446.3	3.2	1.5	.47	245	15.9	
	447.8	3.2	1.8	.56	199	12.9	
	450.2	3.2	2.3	.72	153	9.9	
	458.3	3.3	2.1	.64	168	10.9	
	460.2	3.3	1.6	.48	229	14.9	
	471.1	3.4	1.8	.53	198	12.9	
	473.7	3.4	2.6	.76	137	8.9	*
	476.1	3.4	1.7	.50	213	13.9	
	484.3	3.5	1.4	.40	243	15.9	
	486.1	3.5	2.1	.60	167	10.9	
	494.6	3.6	1.8	.50	197	12.9	
	498.2	3.6	3.4	.94	106	7.0	*
	500.9	3.6	1.6	.44	227	14.9	
	503.5	3.6	3.0	.83	121	7.9	*
	507.8	3.6	2.6	.72	136	8.9	
	511.3	3.7	2.4	.65	151	9.9	
	514.1	3.7	2.2	.59	166	10.9	
	516.5	3.7	2.0	.54	181	11.9	
	518.5	3.7	1.8	.49	196	12.9	
	520.2	3.7	1.7	.46	211	13.9	
	521.7	3.7	1.6	.43	226	14.9	
	523.0	3.8	1.5	.39	241	15.9	
	561.9	4.0	1.5	.38	239	15.9	
	563.2	4.0	1.6	.40	224	14.9	
	564.6	4.1	1.7	.41	209	13.9	

① Provides uniformly spaced ground tracks along Equator with spacing $\leq$ footprint width.
② Along Equator.

Table A-3 - Optimum Orbit Altitudes, Inclination 70.0 Degrees, Altitude Range 185 to 600 Kilometers
(Sheet 3 of 3)

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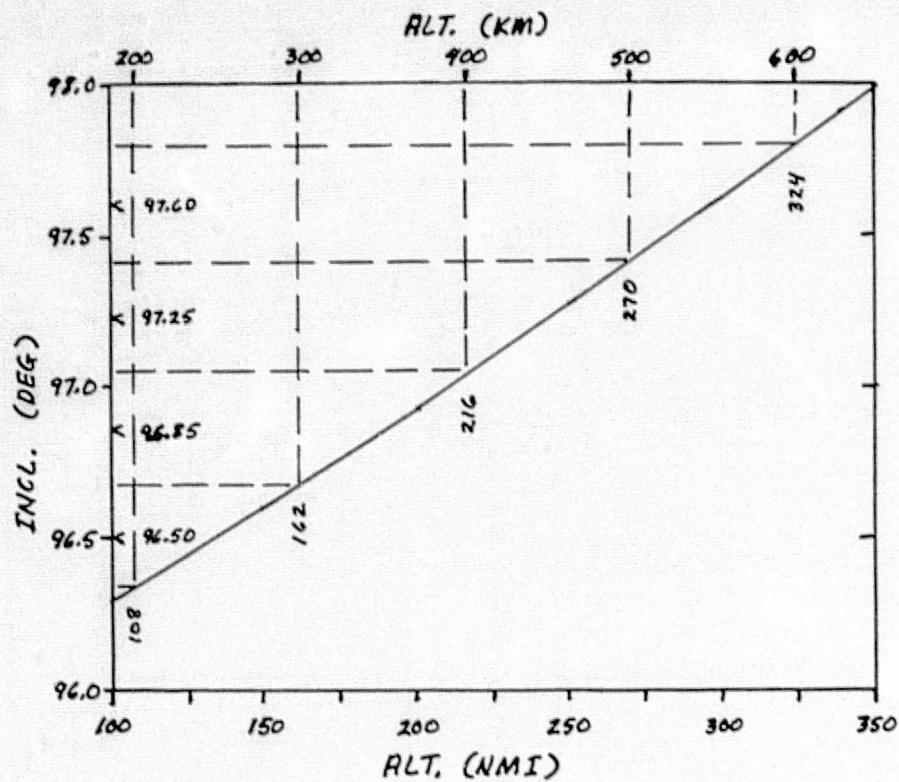


Figure A-1 — Inclinations for sun-synchronous polar orbits versus altitude

Table A-4 - Optimum Orbit Altitudes and Inclinations for Sun-Synchronous Orbits,
Altitude Range 185 to 600 Kilometers (Sheet 1 of 3)

Orbit Incl. (Deg.)	Useful ^① Altitudes (Kms)	Footprint Width ^② (Deg.)	Grnd. Track Spacing (Deg.)	Effic. GT5+FW —	Revs. To Close (#)	Time To Close (Days)	
96.4	221.9	1.5	1.5	.98	244	15.0	
96.5	258.2	1.8	1.5	.94	242	15.0	
96.6	273.7	1.9	1.7	.93	209	13.0	
96.6	275.2	1.9	1.6	.95	225	14.0	
96.6	276.5	1.9	1.5	.90	241	15.1	
96.7	313.5	2.1	1.5	.69	239	15.1	
96.7	314.8	2.1	1.1	.75	223	14.0	
96.7	316.3	2.1	1.8	.83	207	13.0	
96.7	318.2	2.2	1.9	.87	191	12.0	
96.8	320.2	2.2	2.1	.97	175	11.0	
96.8	332.2	2.3	1.5	.66	238	15.1	
96.8	338.0	2.3	1.8	.76	206	13.0	
96.8	345.9	2.4	2.1	.87	174	11.0	
96.9	355.0	2.4	1.7	.70	221	14.0	
96.9	360.0	2.5	1.7	.71	205	13.0	
96.9	376.0	2.5	1.5	.61	236	15.1	
96.9	371.7	2.5	2.1	.84	173	11.0	
97.0	379.6	2.6	2.3	.88	157	10.0	
97.0	381.9	2.6	1.7	.67	204	13.0	
97.0	395.9	2.7	1.7	.63	219	14.0	
97.0	397.8	2.7	2.1	.79	172	11.0	
97.1	403.9	2.8	1.8	.65	203	13.0	
97.1	413.2	2.8	2.0	.70	187	12.0	
97.1	419.3	2.9	1.4	.51	249	16.0	
97.1	421.3	2.9	2.6	.90	140	9.0	
97.1	424.3	2.9	2.1	.73	171	11.0	
97.1	426.3	2.9	1.8	.61	202	13.0	
97.1	427.6	2.9	1.5	.53	233	15.1	
97.2	447.2	3.0	1.6	.53	232	15.1	
^① Provides uniformly spaced ground tracks along Equator with spacing $\leq$ footprint width. ^② Along Equator.							

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Table A-4 - Optimum Orbit Altitudes and Inclinations for Sun-Synchronous Orbits,
Altitude Range 185 to 600 Kilometers (Sheet 2 of 3)

Orbit Incl. (Deg.)	Useful ^① Altitudes (Km)	Footprint Width ^② (Deg.)	Gnd. Track Spacing (Deg.)	Effic. GTS ÷ FW —	Revs. To Close (#)	Time To Close (Days)
97.2	448.7	3.1	1.9	.61	201	13.0
97.2	450.7	3.1	2.2	.71	170	11.0
97.2	453.7	3.1	2.7	.86	139	9.0
97.2	456.0	3.1	1.4	.46	247	16.1
97.3	462.0	3.1	1.9	.62	185	12.0
97.3	471.5	3.2	1.8	.57	200	13.0
97.3	474.3	3.2	2.9	.91	123	7.0
97.3	477.8	3.3	2.1	.65	169	11.0
97.3	479.6	3.3	1.7	.52	215	14.0
97.4	493.0	3.4	1.5	.44	245	16.0
97.4	494.5	3.4	1.7	.53	199	13.0
97.4	496.7	3.4	2.4	.70	153	10.0
97.4	500.9	3.4	3.4	.99	107	7.0
97.4	504.8	3.4	2.2	.63	168	11.0
97.4	506.7	3.5	1.6	.46	239	15.1
97.5	517.6	3.5	1.7	.50	198	13.0
97.5	520.0	3.5	2.7	.75	137	9.0
97.5	522.4	3.6	1.7	.48	213	14.0
97.5	530.6	3.6	1.5	.42	243	16.0
97.5	532.2	3.6	2.2	.61	167	11.0
97.6	540.7	3.7	1.9	.50	197	13.0
97.6	544.1	3.7	3.4	.92	106	7.0
97.6	547.0	3.7	1.6	.43	237	15.1
97.6	549.5	3.7	3.0	.70	121	8.0
97.6	553.9	3.7	2.6	.70	136	9.0
97.6	557.2	3.7	2.4	.64	151	10.0
97.6	560.0	3.7	2.2	.57	166	11.0
97.7	562.4	3.8	2.0	.52	181	12.0
97.7	564.3	3.8	1.8	.48	196	13.0

① Provides uniformly spaced ground tracks along Equator with spacing $\leq$ footprint width.

② Along Equator.

Table A-4 — Optimum Orbit Altitudes and Inclinations for Sun-Synchronous Orbits,
Altitude Range 185 to 600 Kilometers (Sheet 3 of 3)

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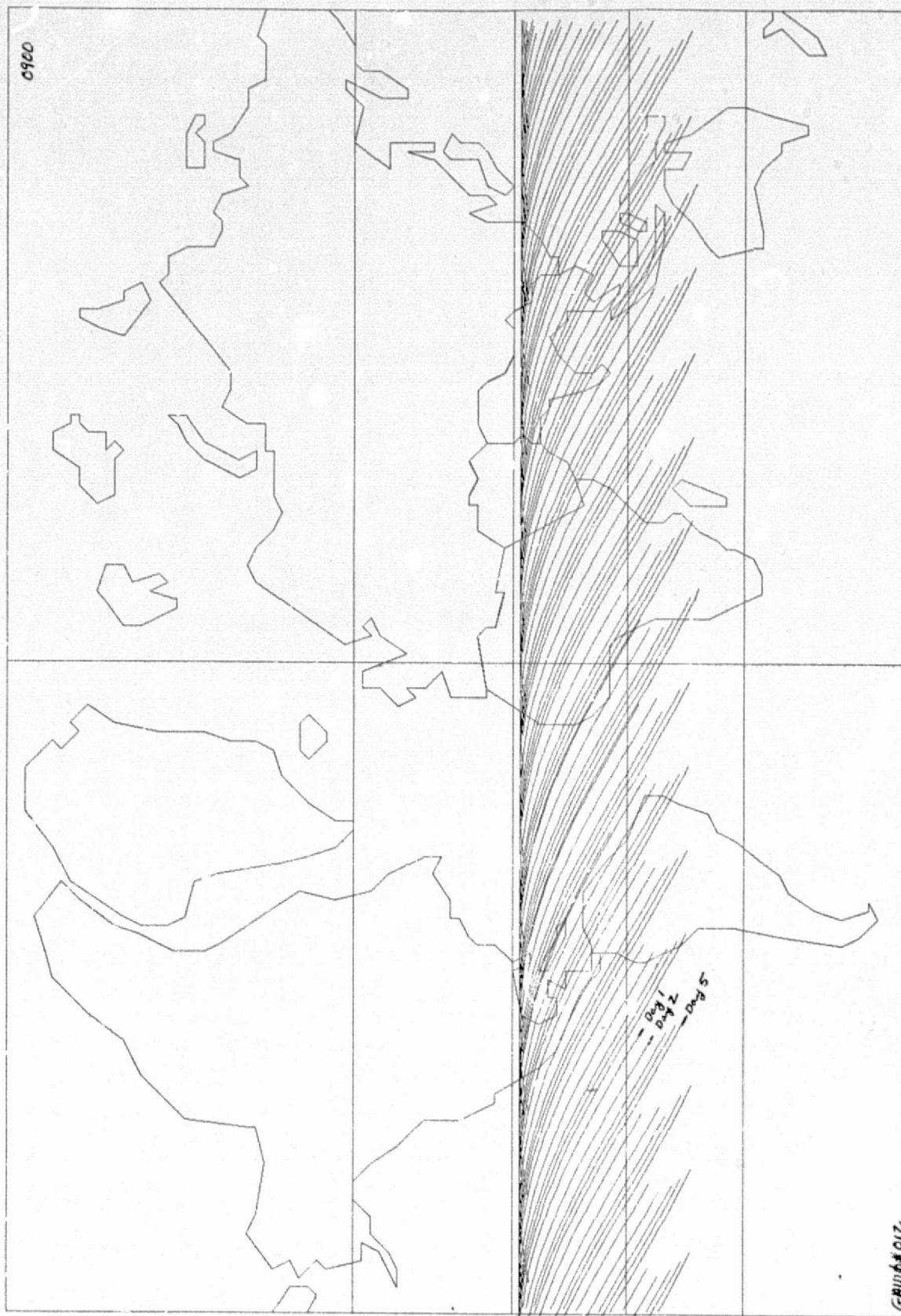
Appendix B

LAUNCH TIME SELECTION DATA

FIGURE PACK 1 - STS-9 ILLUMINATION CONDITIONS

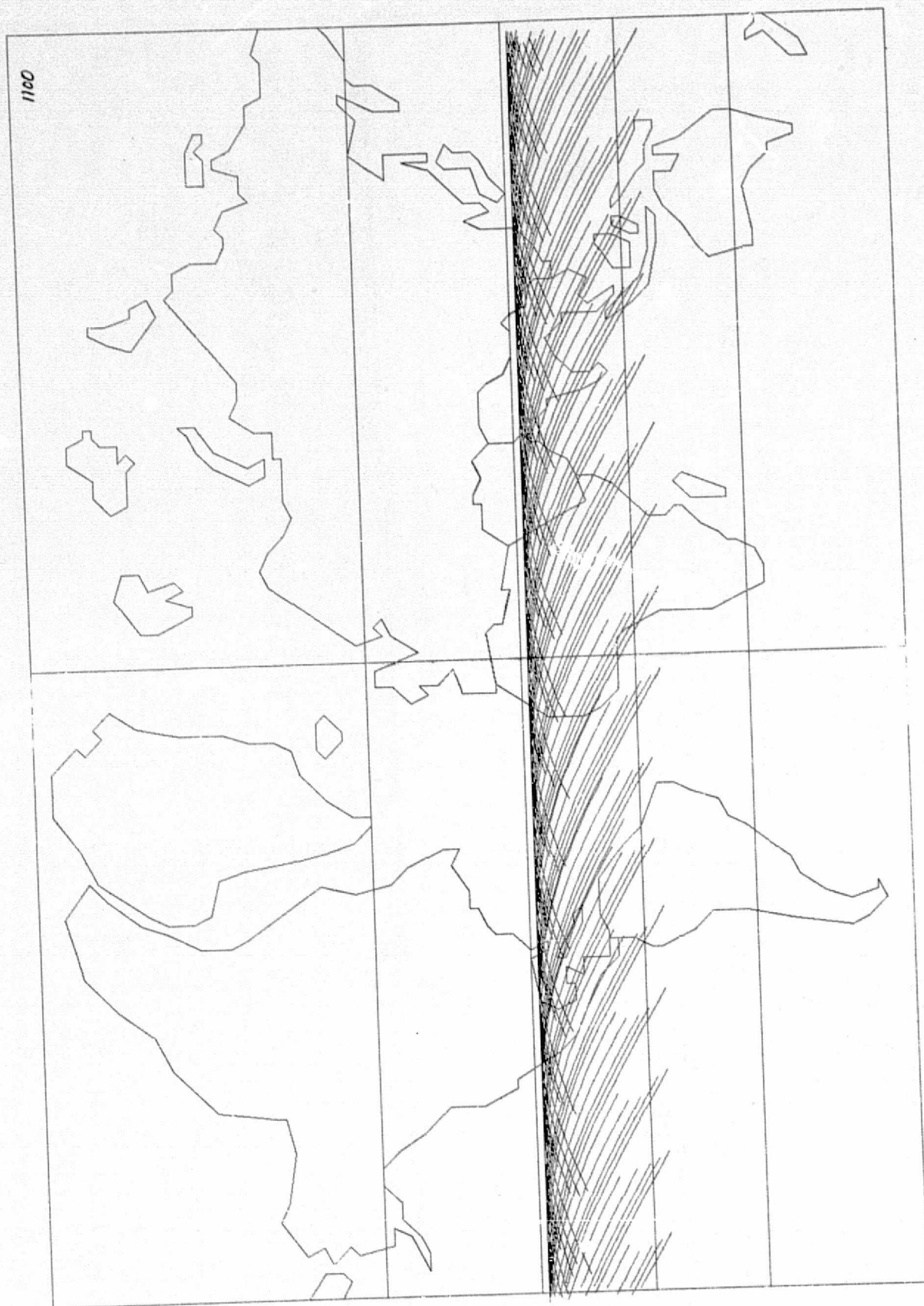
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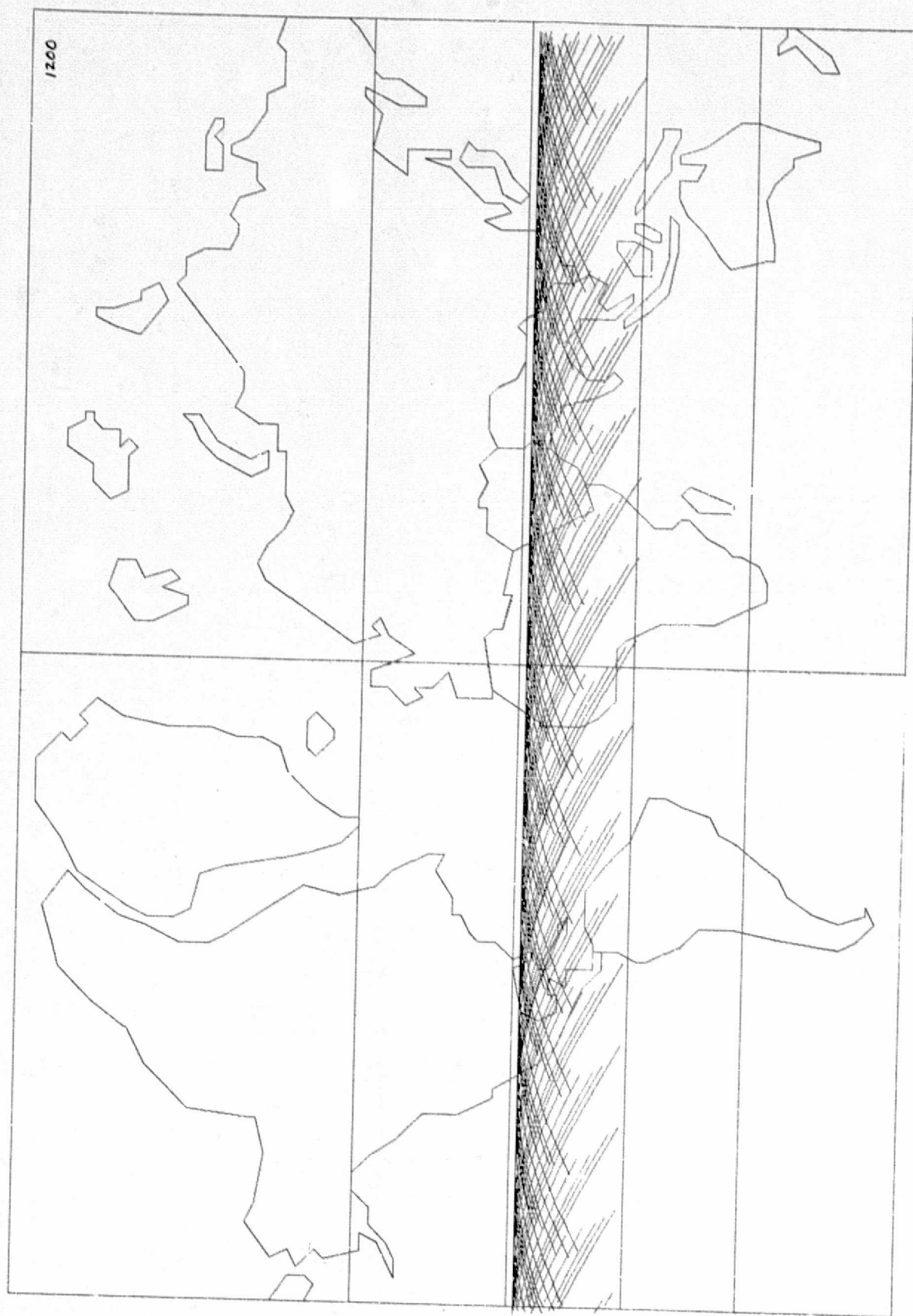
Launch date	1 August
Launch time	0900 to 1500 hours
Solar Altitude	30 degrees or greater

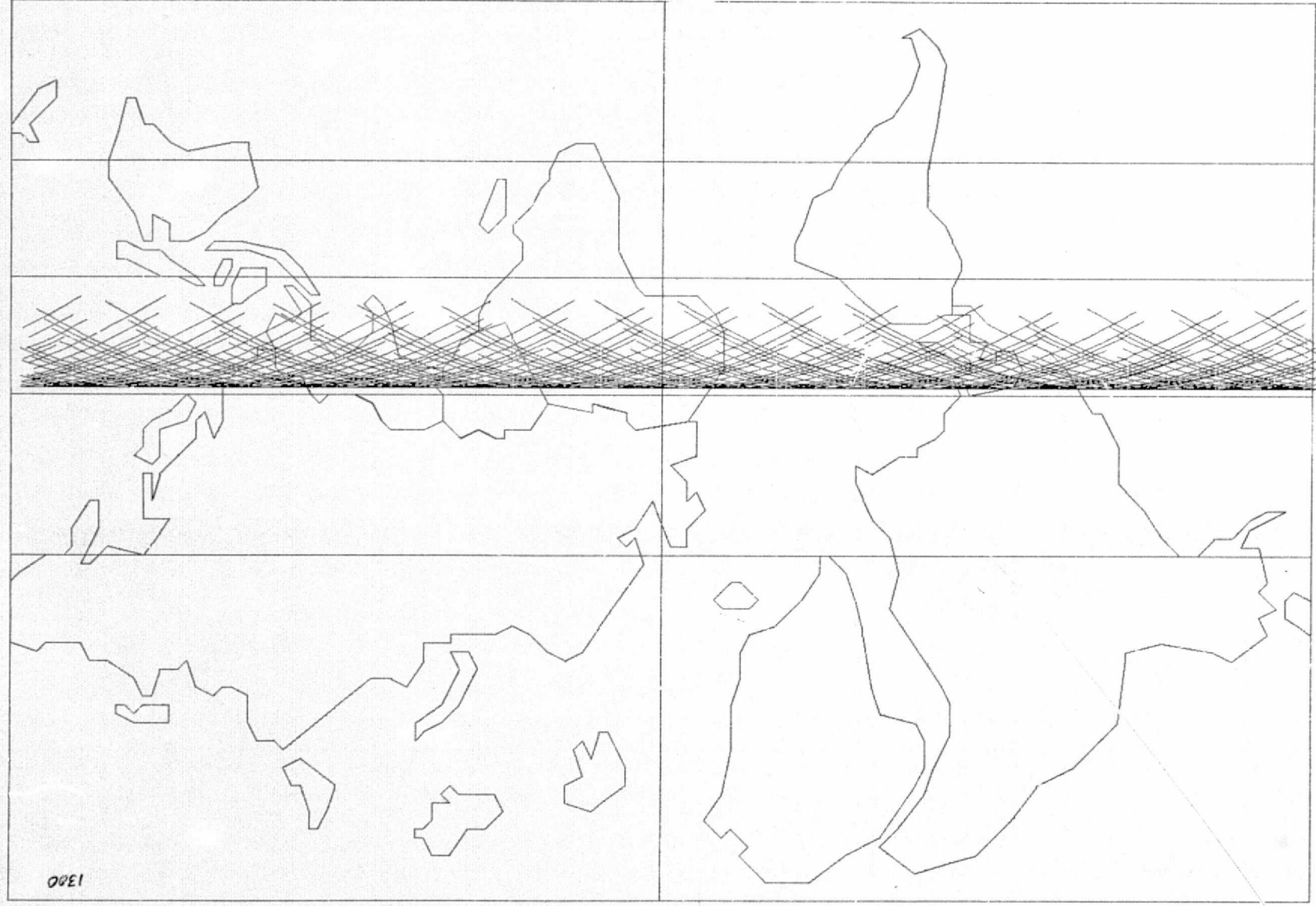


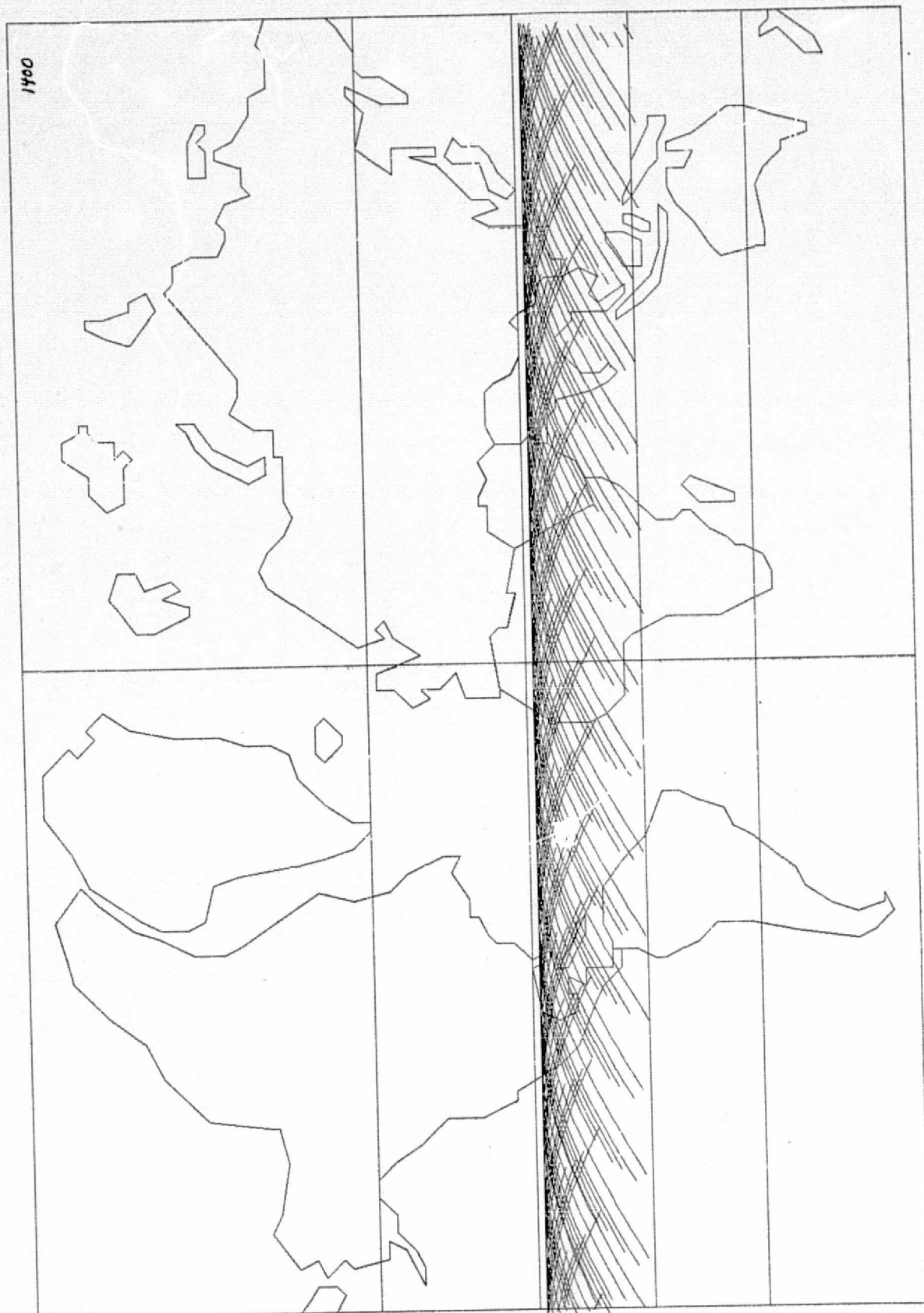


020









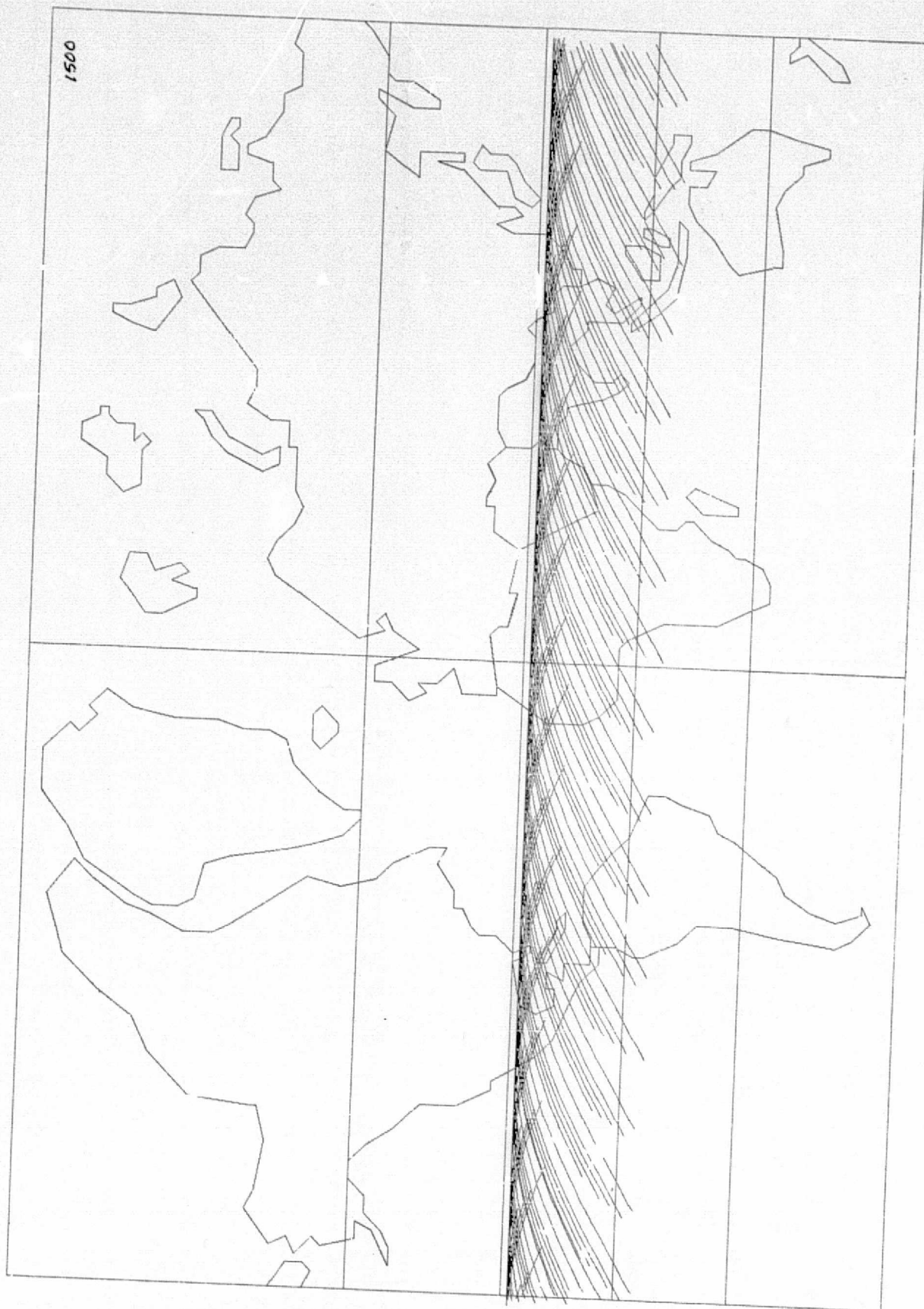
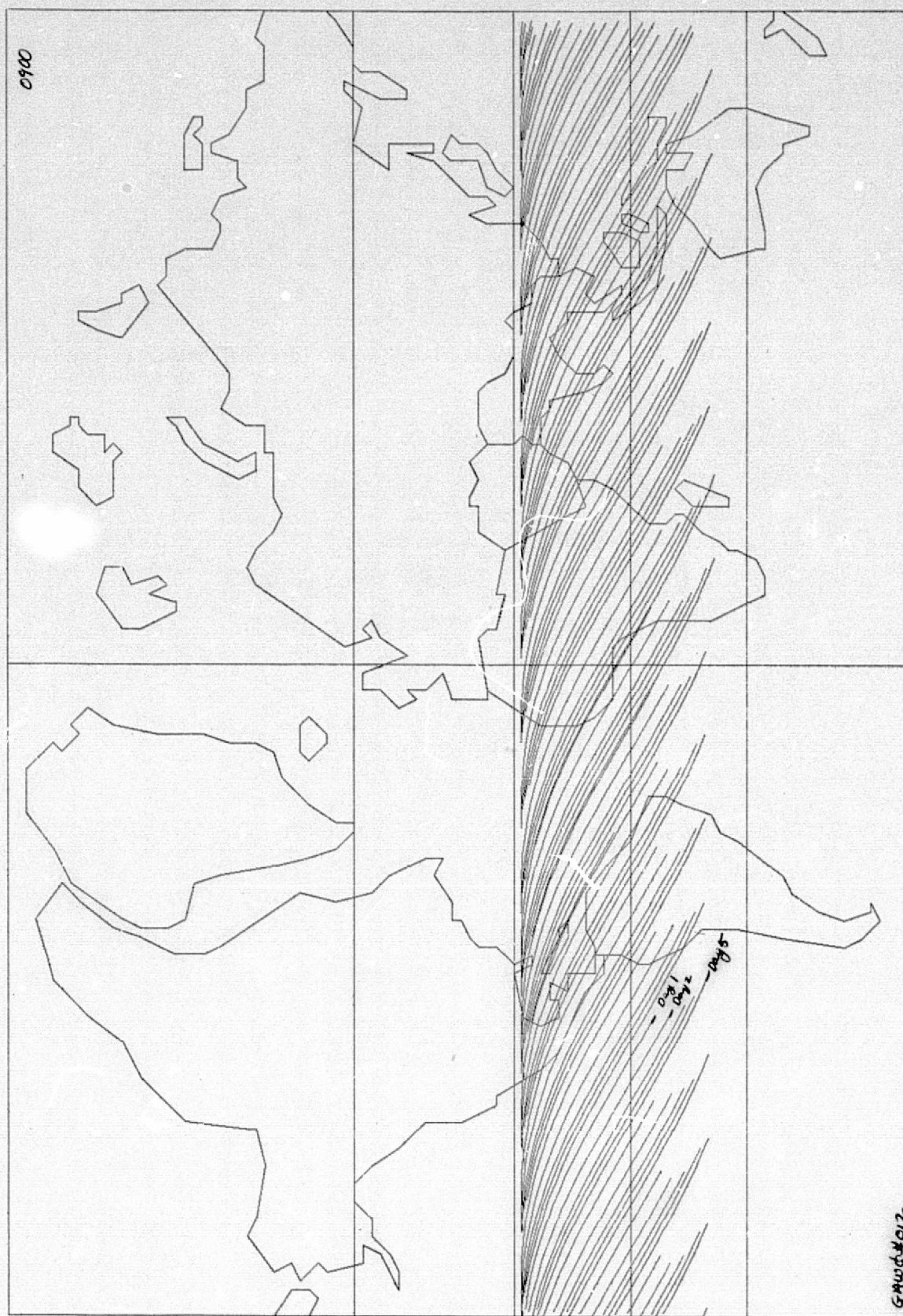
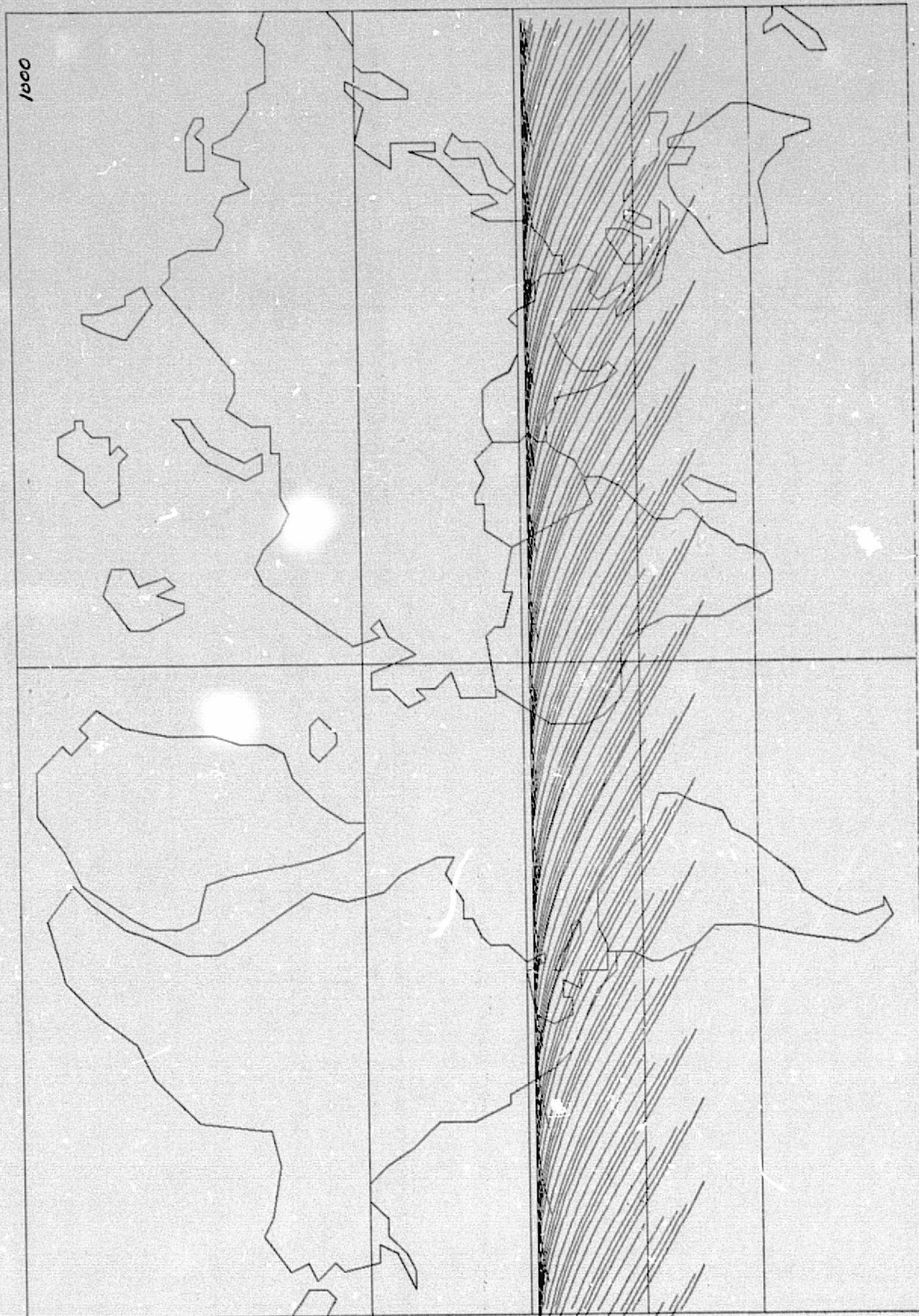


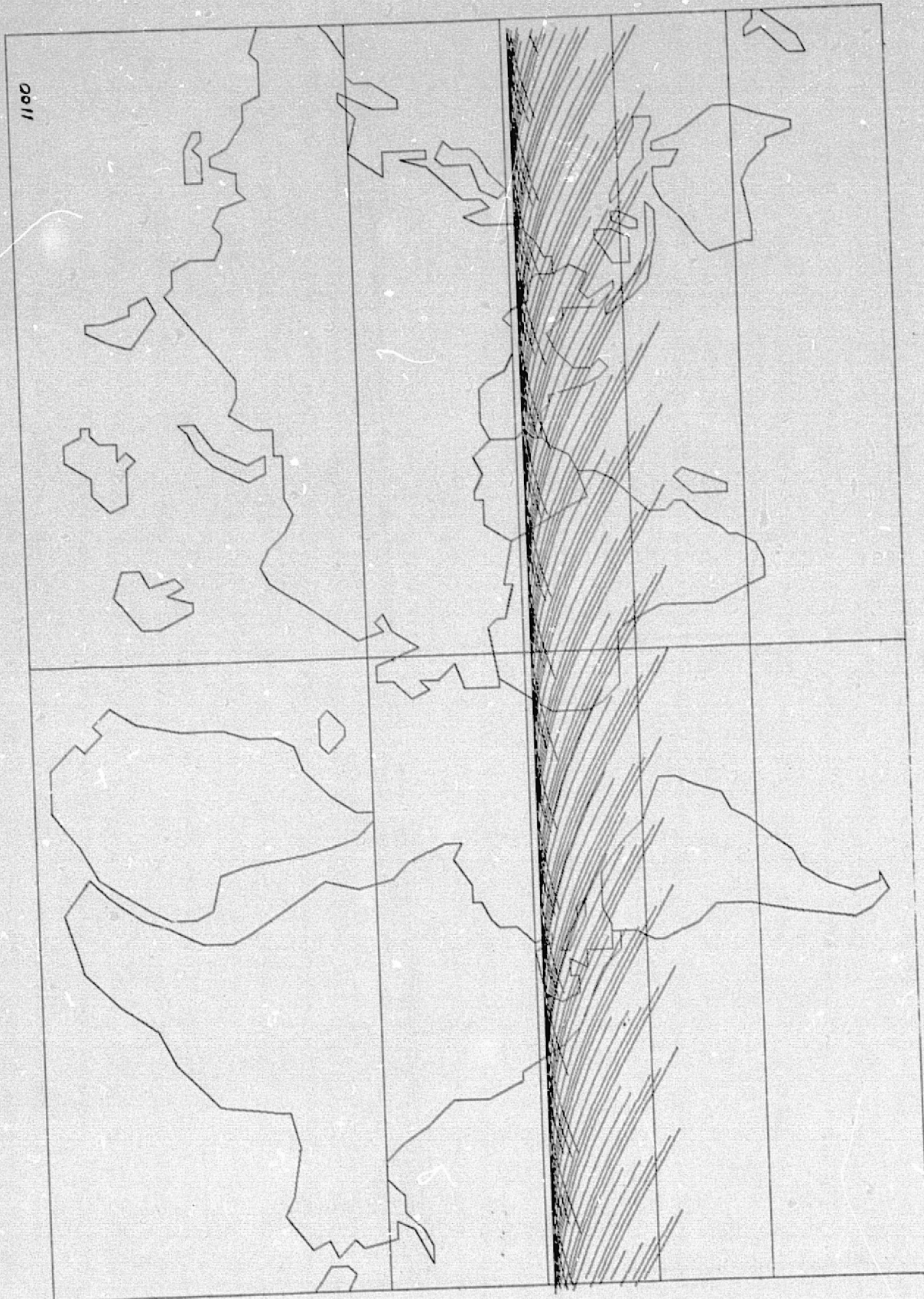
FIGURE PACK 2 - STS-9 ILLUMINATION CONDITIONS

Data:

Launch date	1 October
Launch time	0900 to 1500 hours
Solar altitude	30 degrees or greater



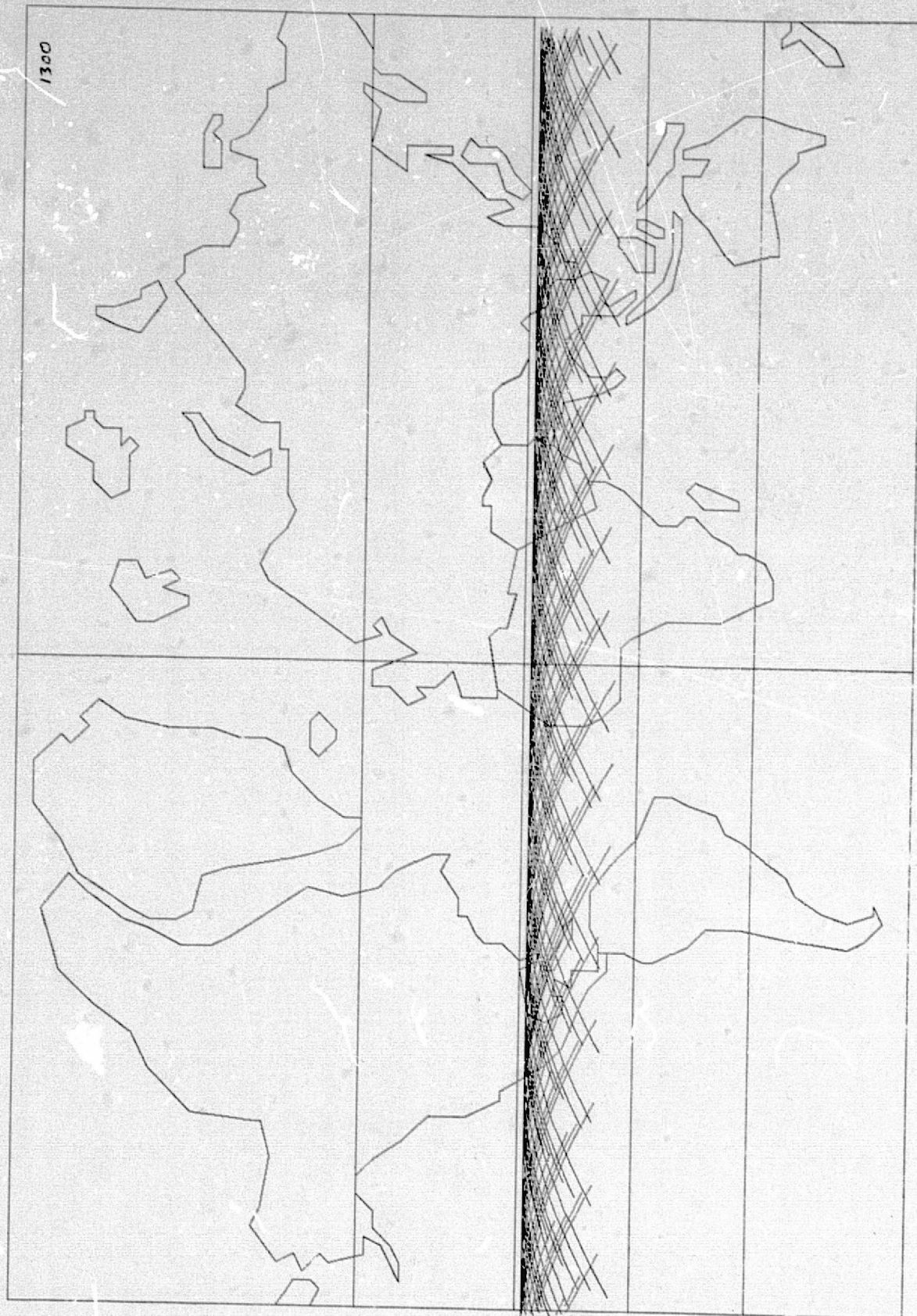


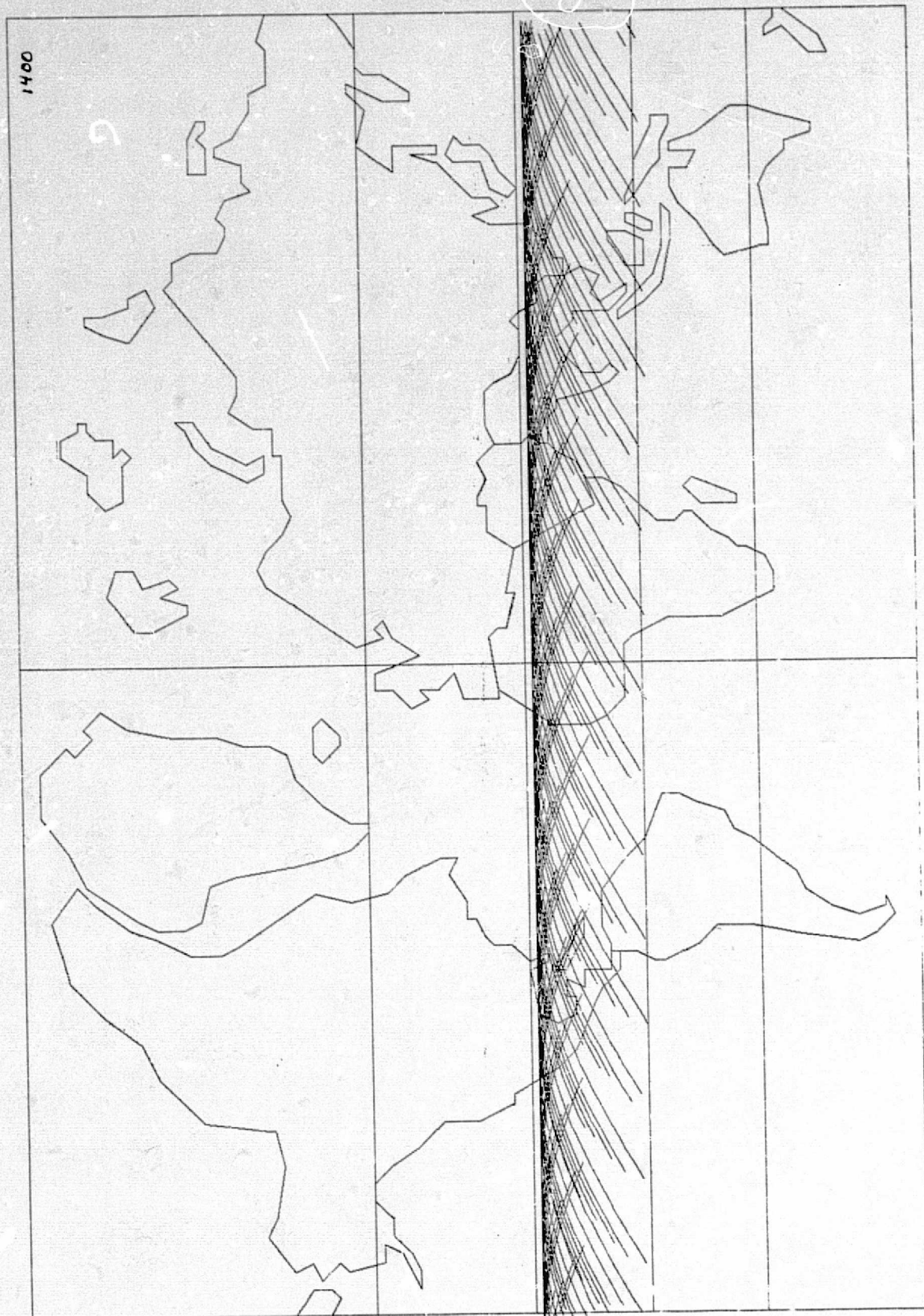


1100

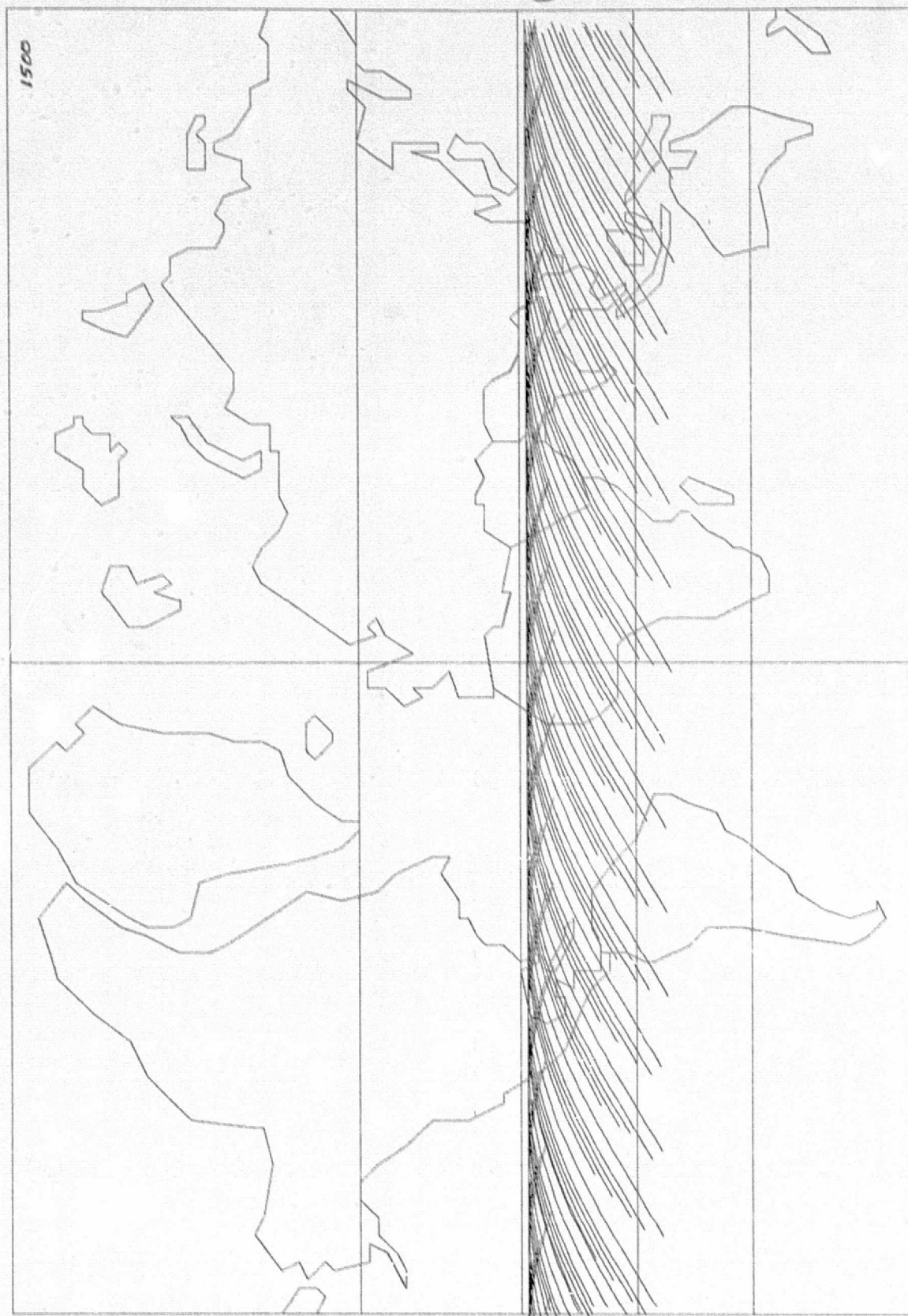
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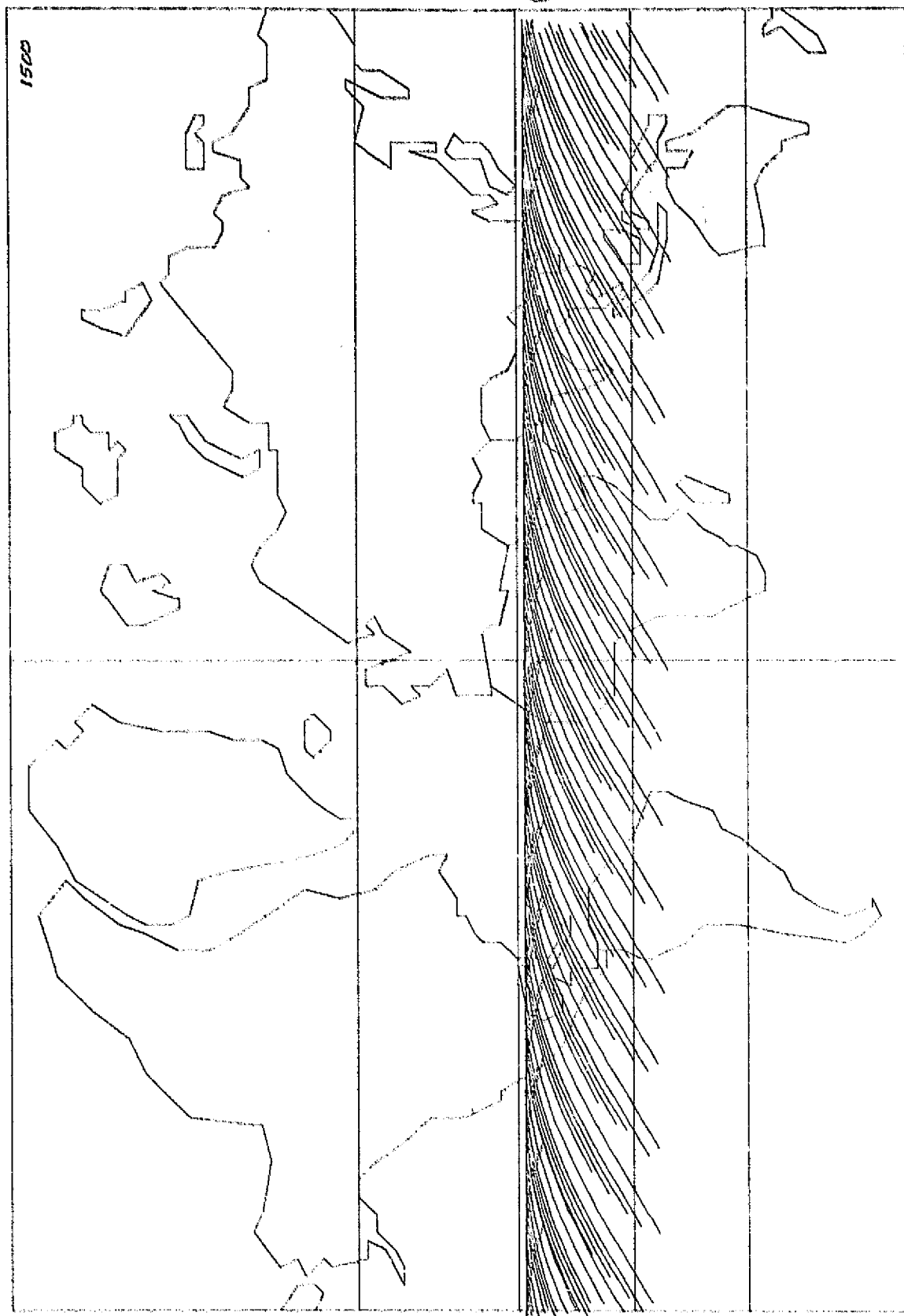
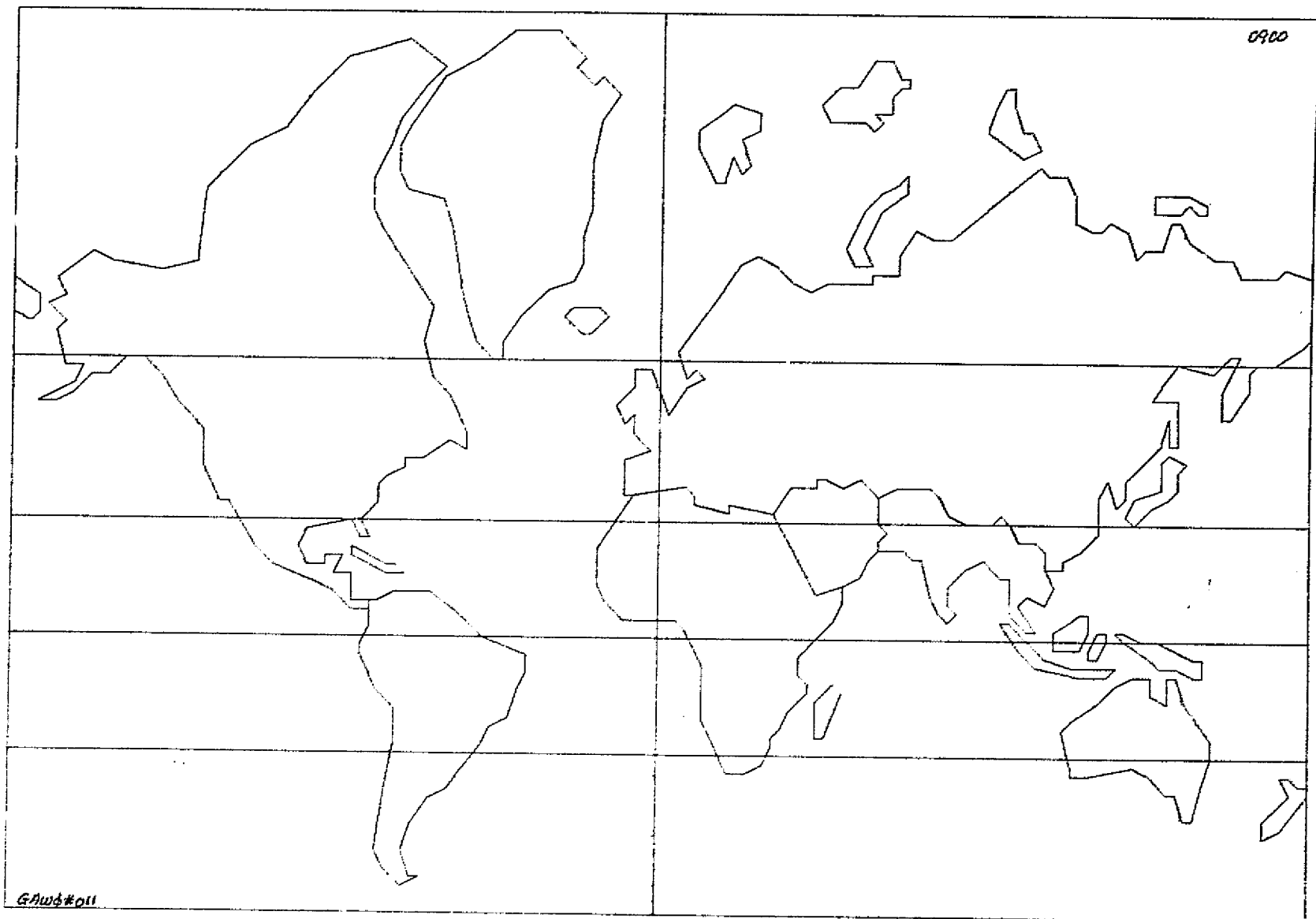
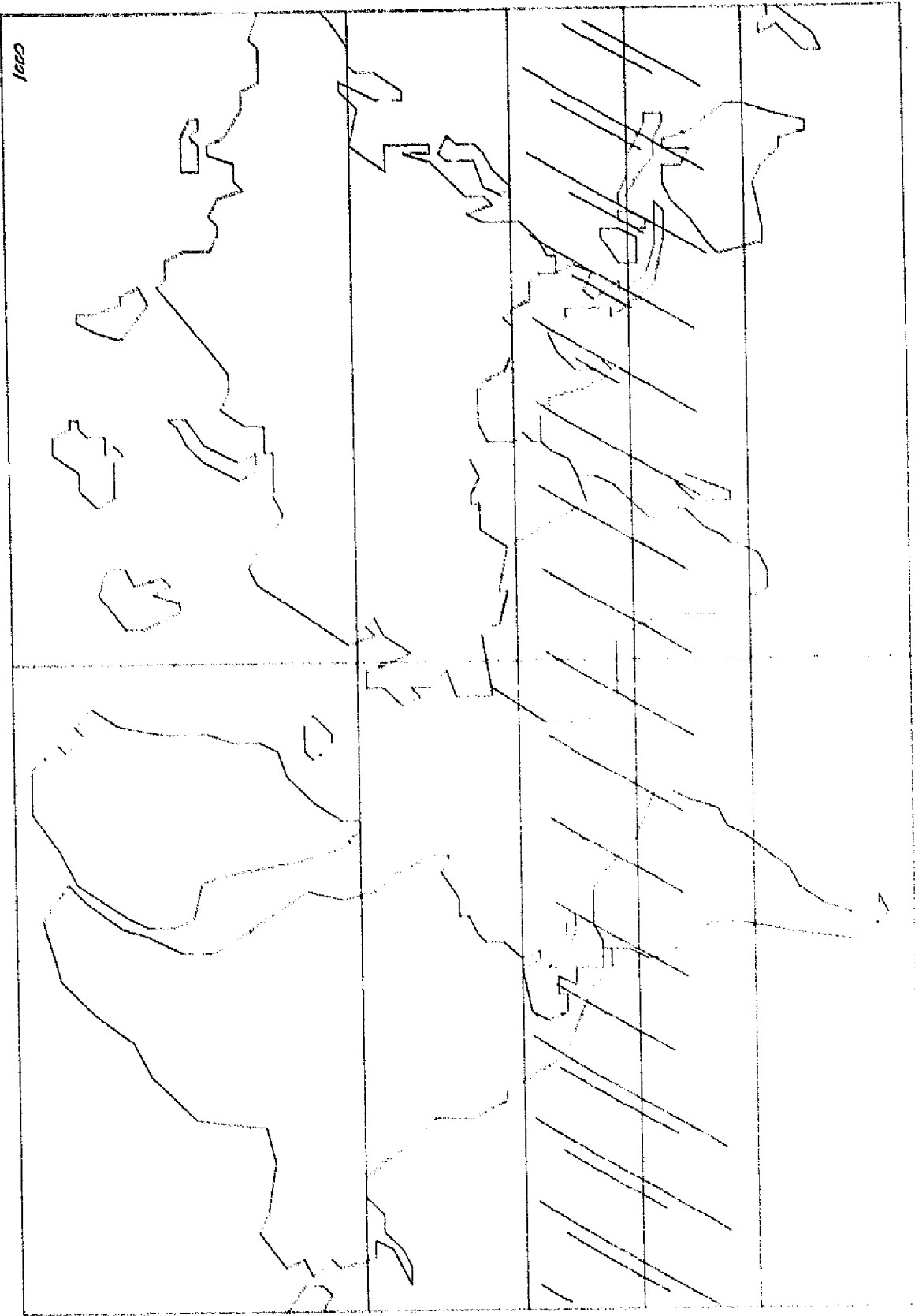


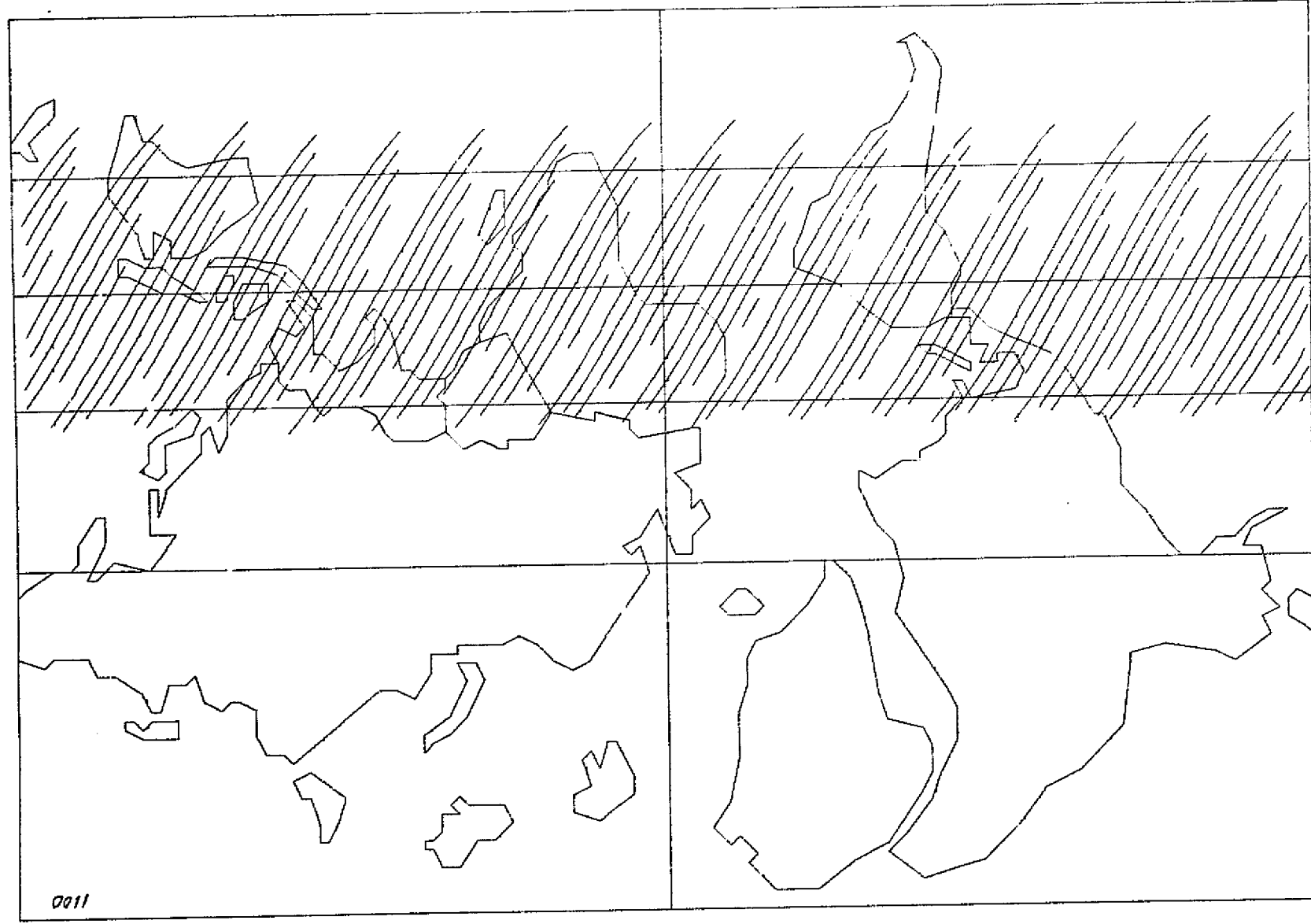
FIGURE PACK 3 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

Data:

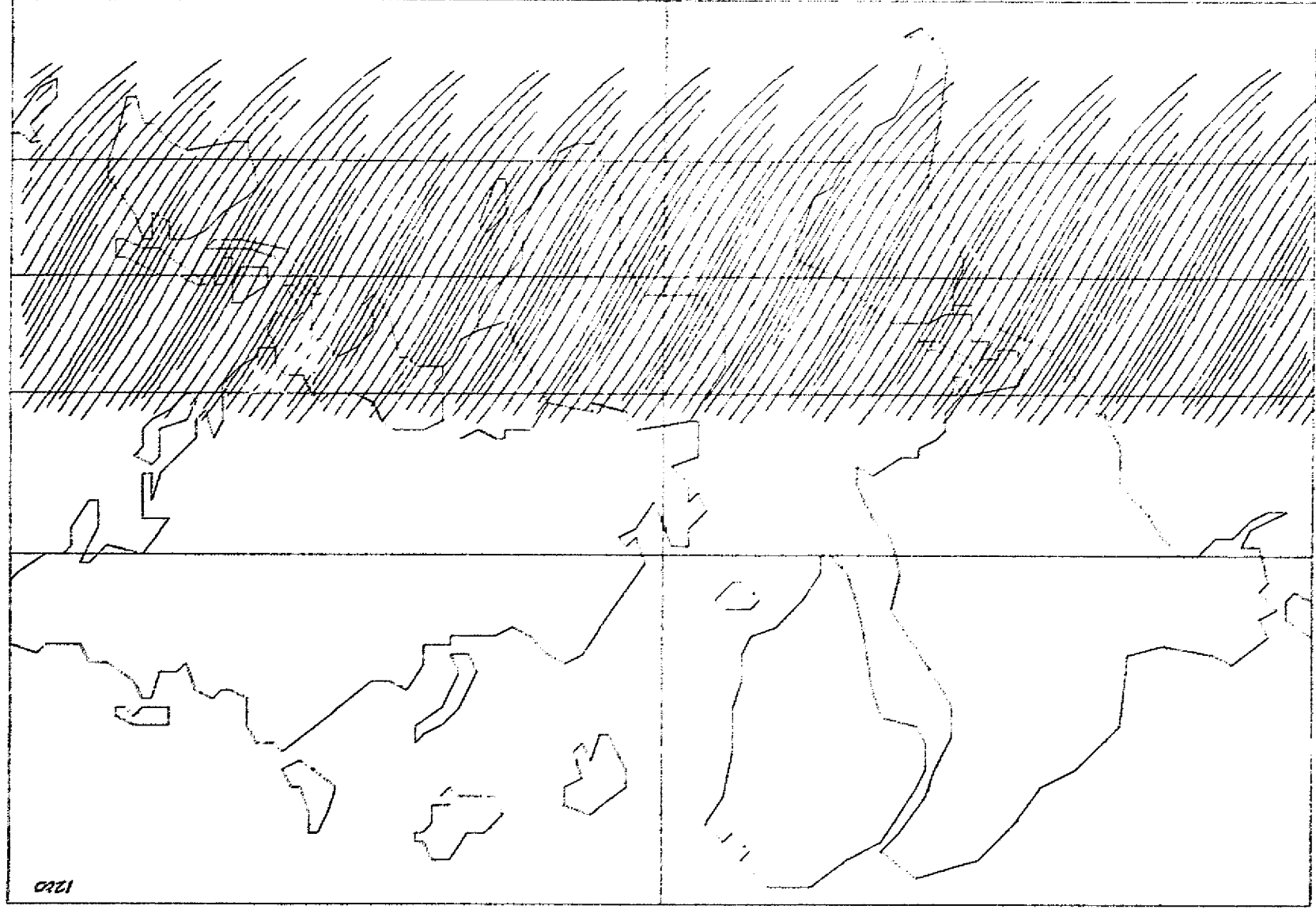
Launch site	KSC
Inclination	57 degrees
Altitude	275.9 kilometers
Launch date	1 January
Launch time	0900 to 1500 hours (hourly)

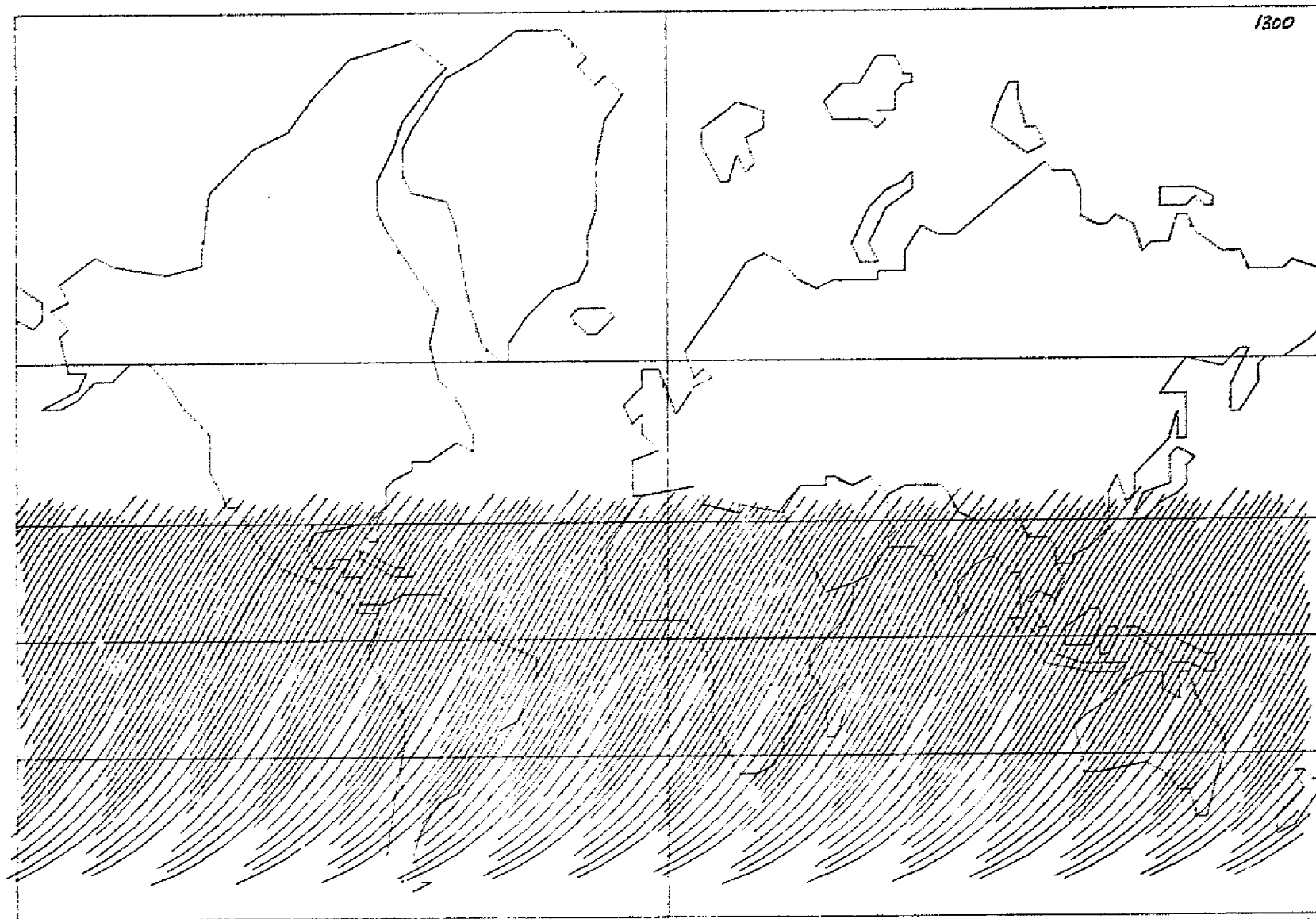






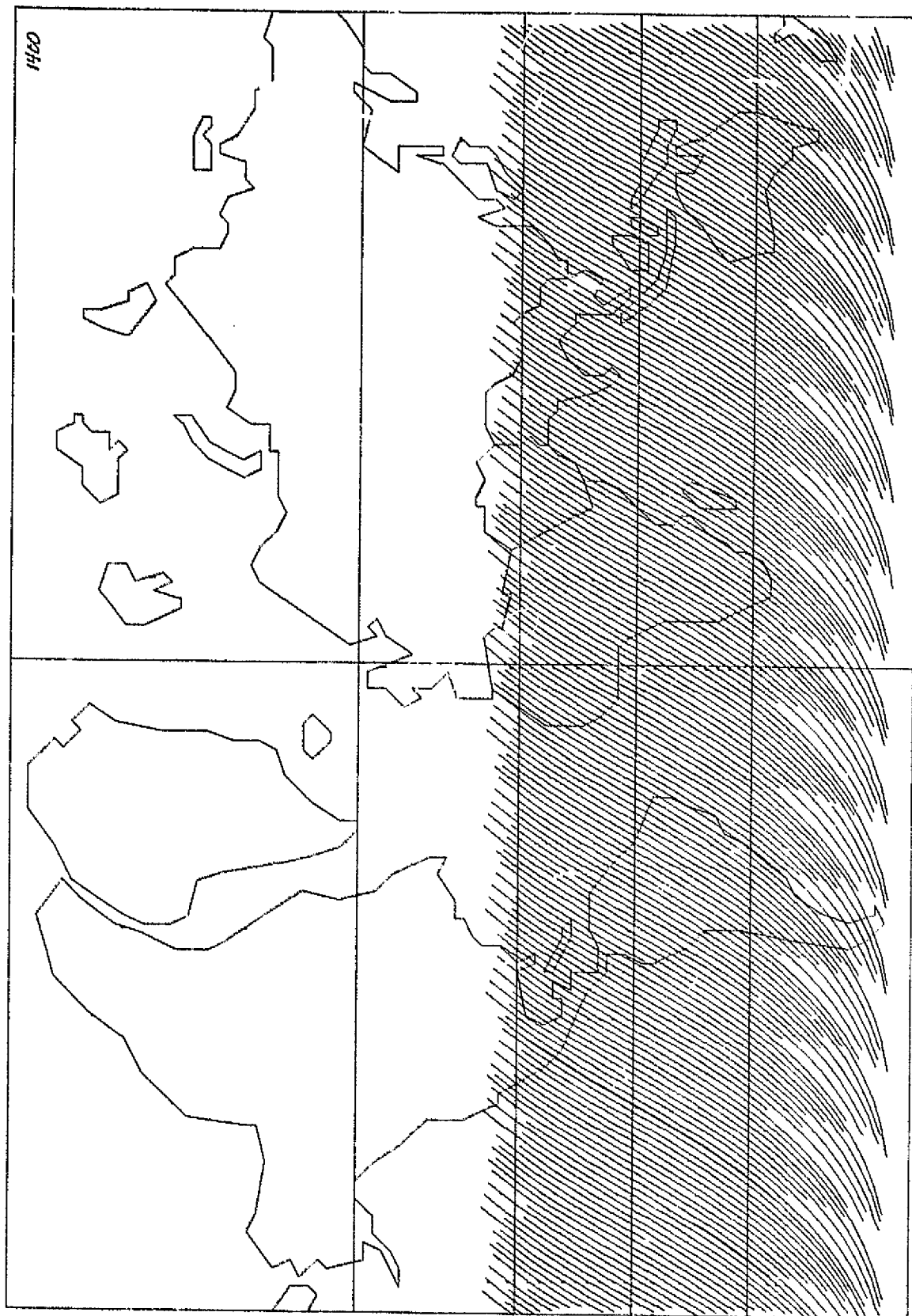
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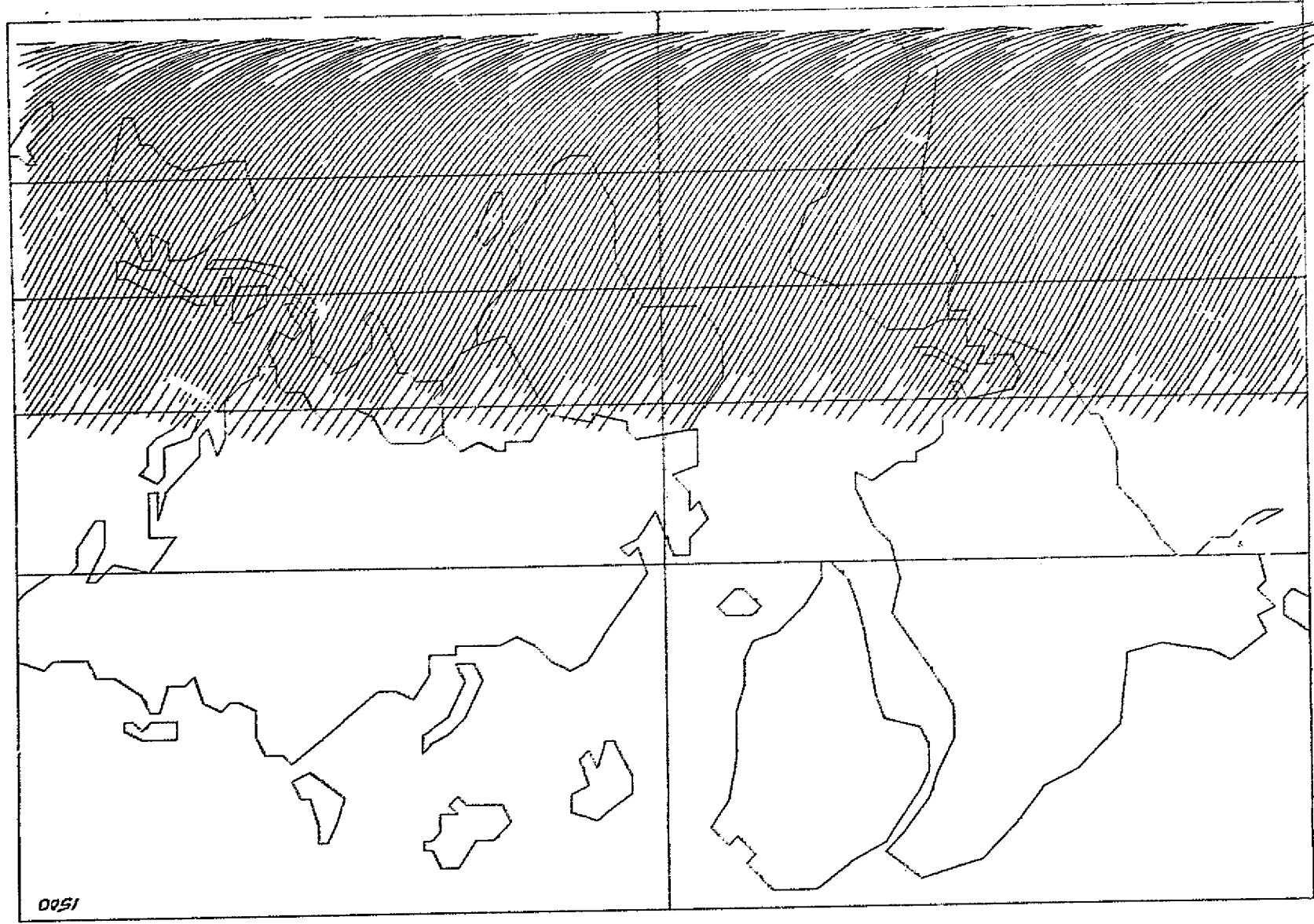


FIGURE PACK 4 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

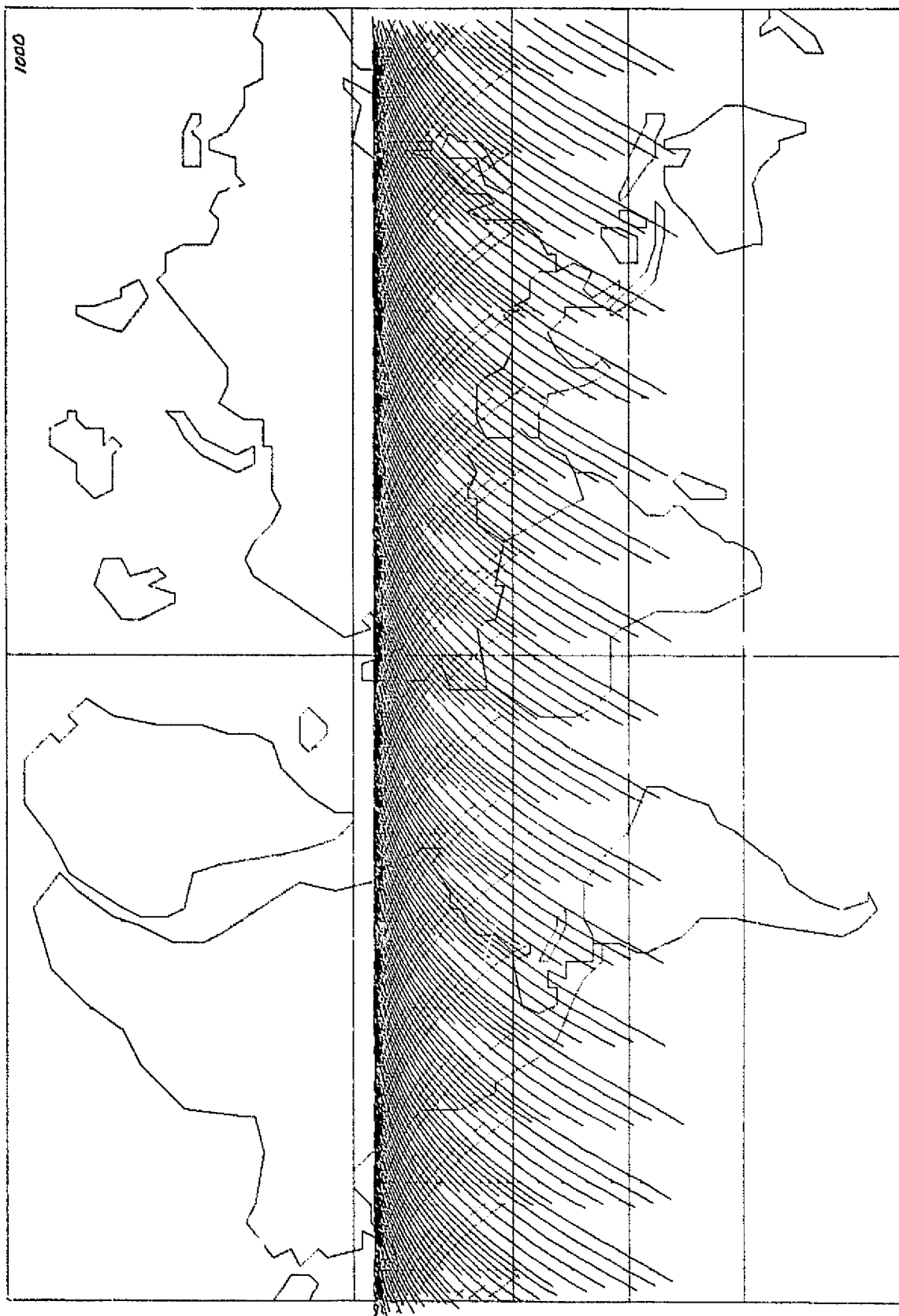
Data:

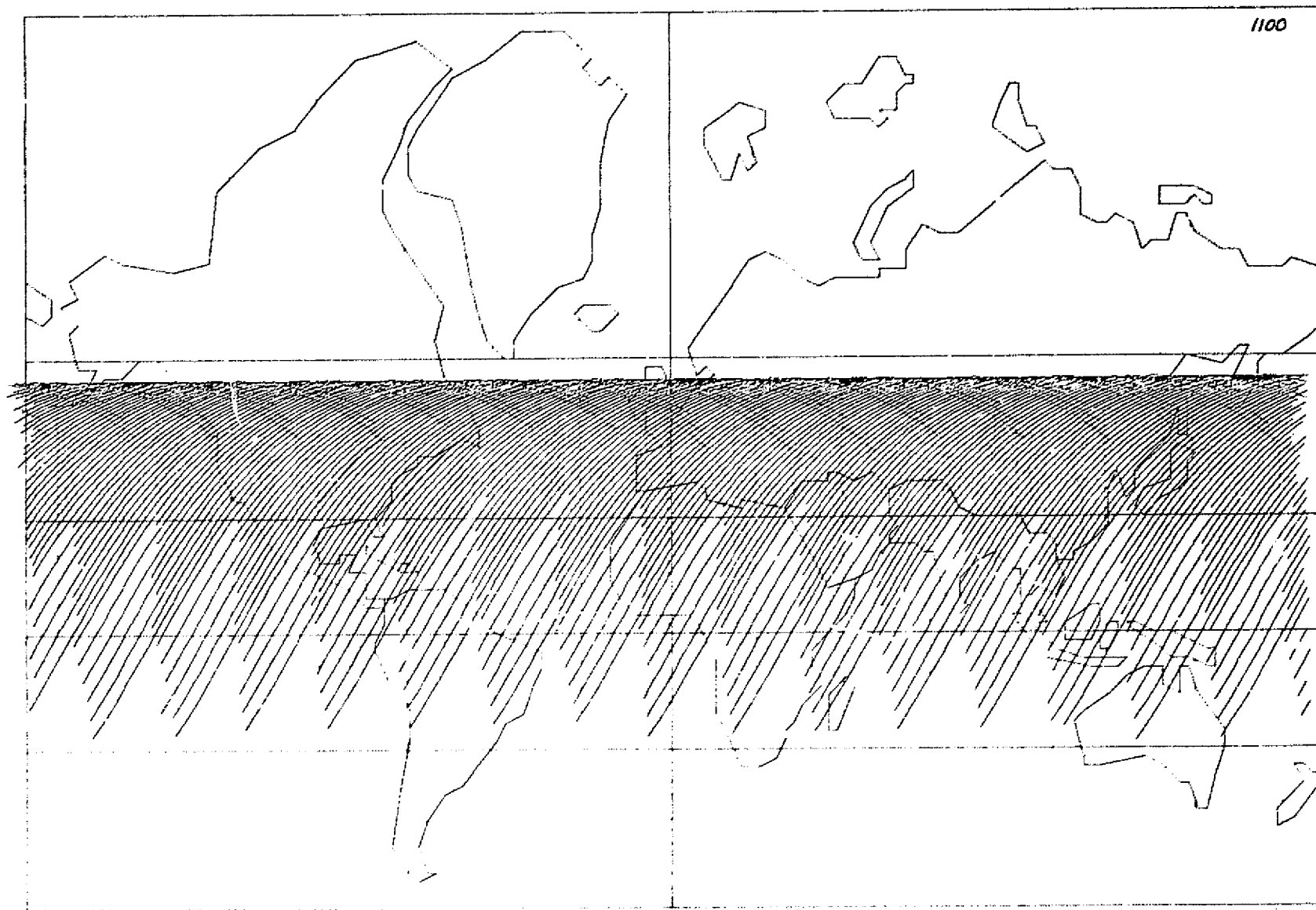
Launch site	KSC
Inclination	57 degrees
Altitude	275.9 kilometers
Launch date	1 April
Launch time	0900 to 1500 hours (hourly)

6900

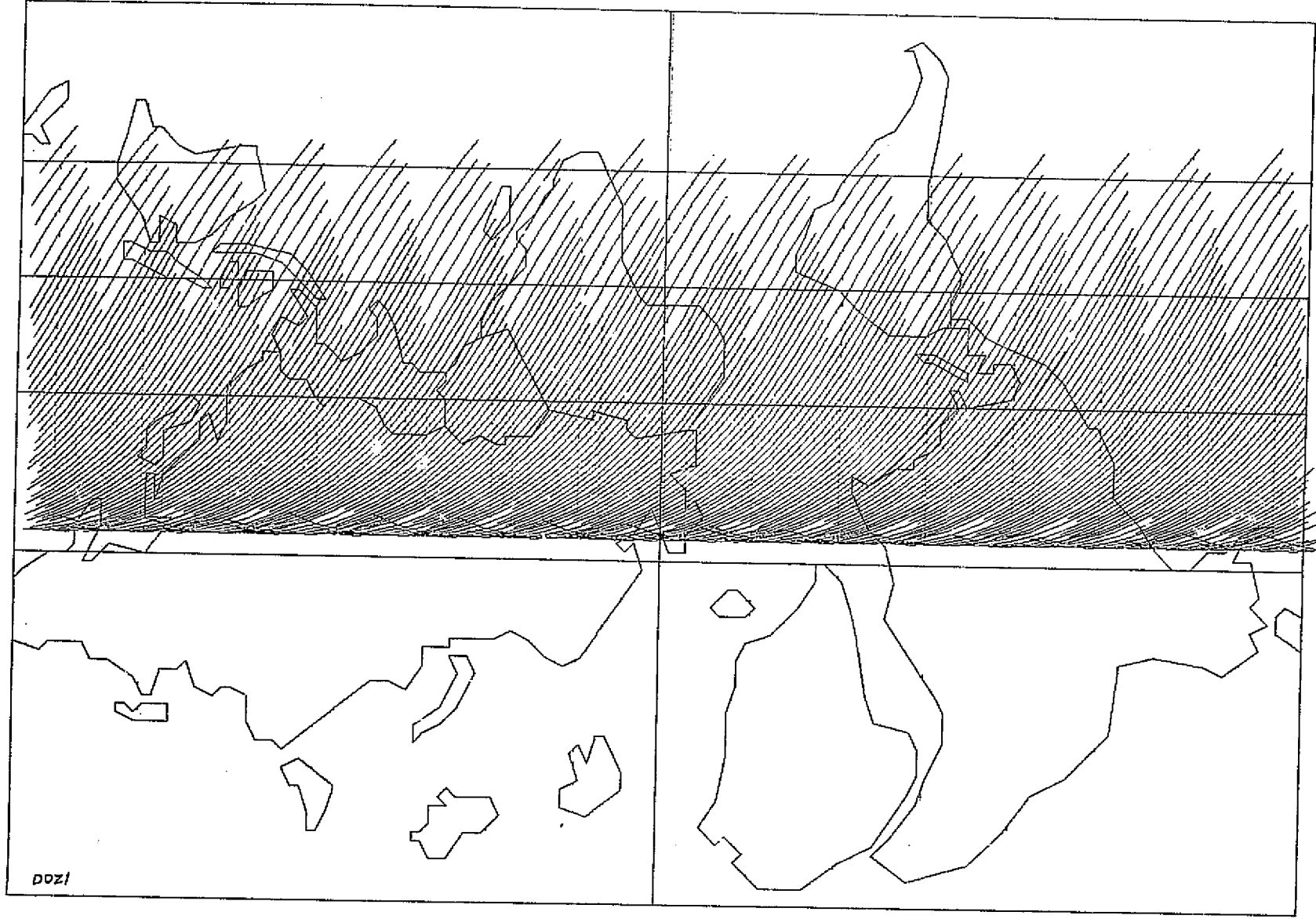
6900 #011

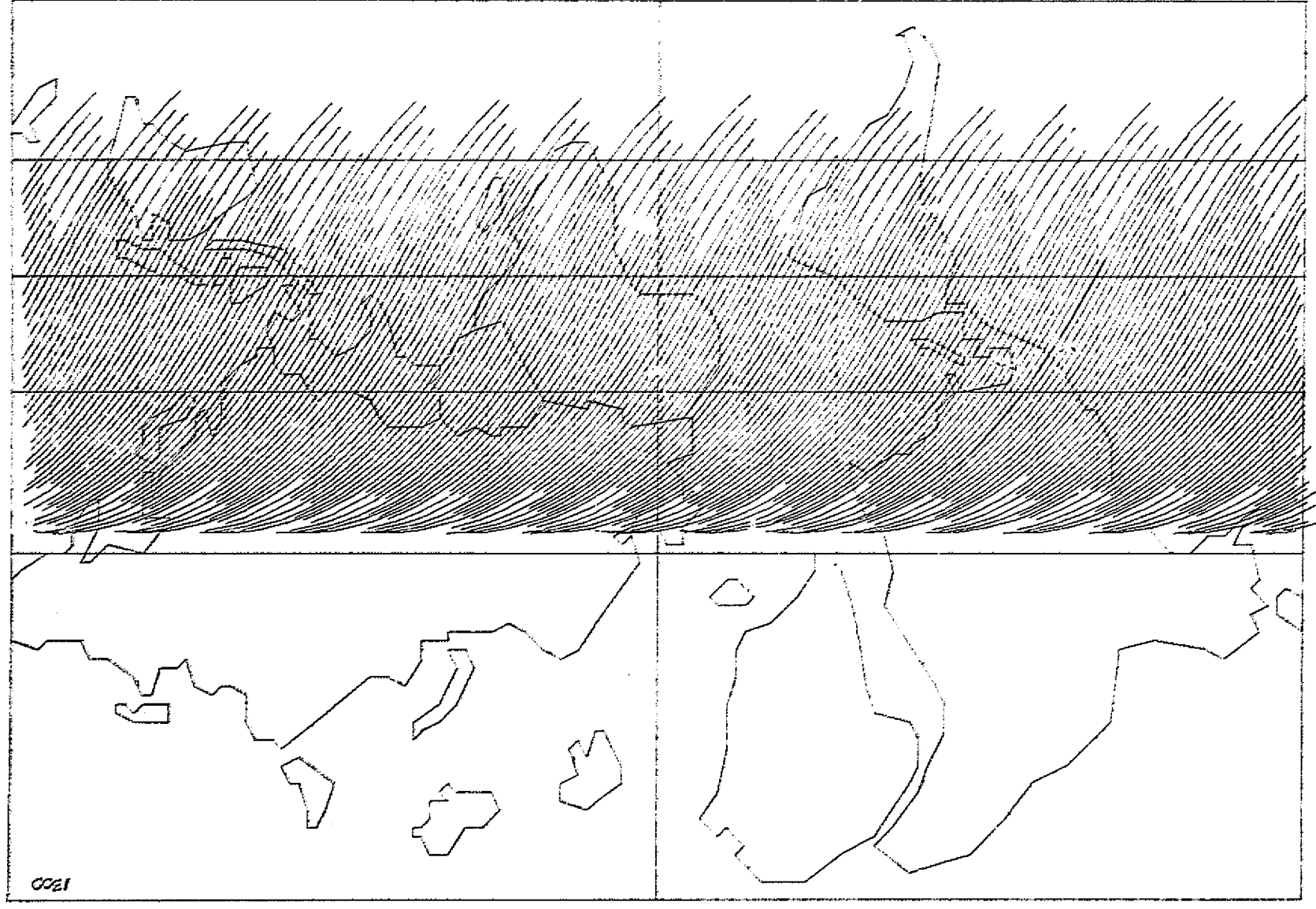
B-28



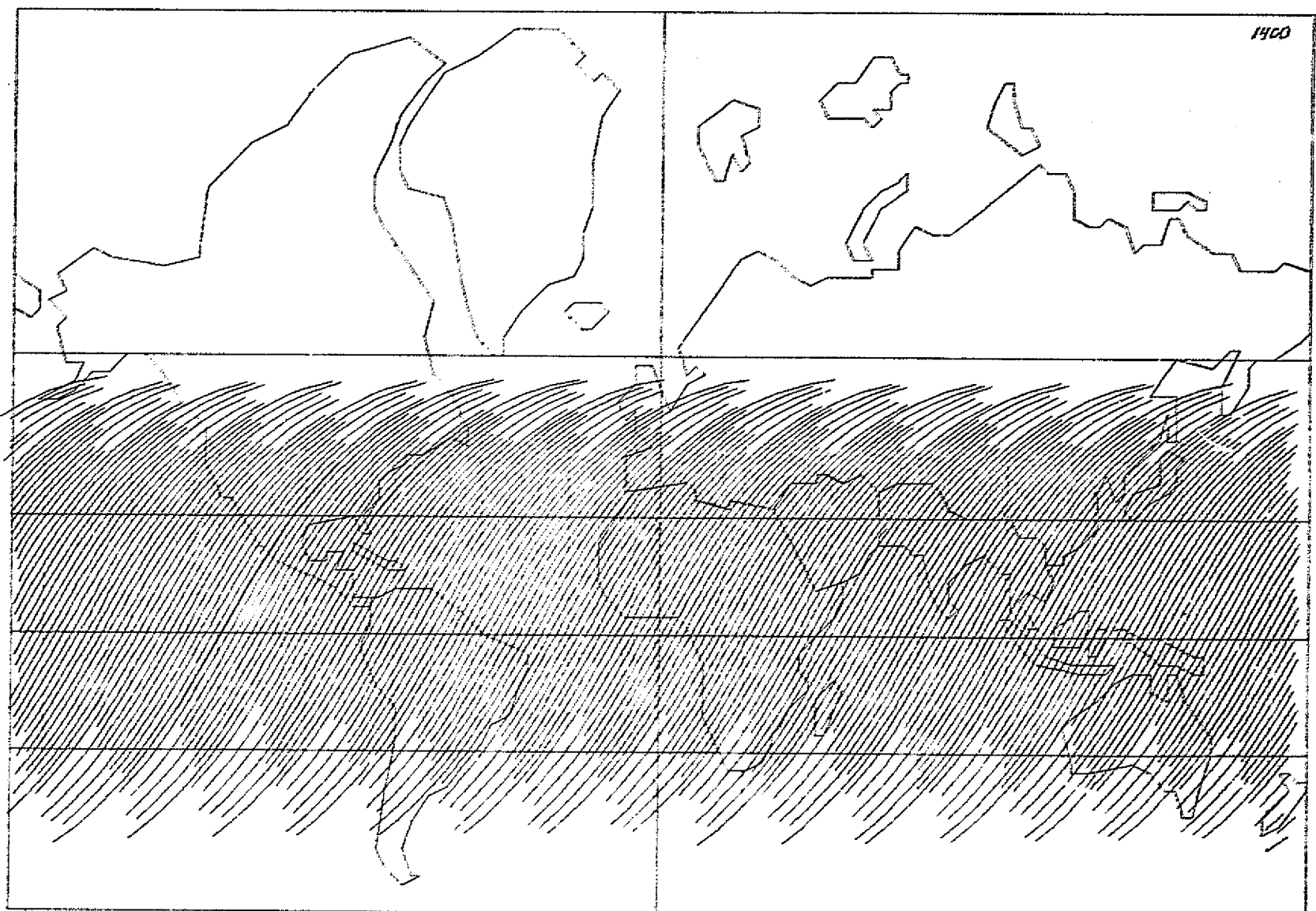


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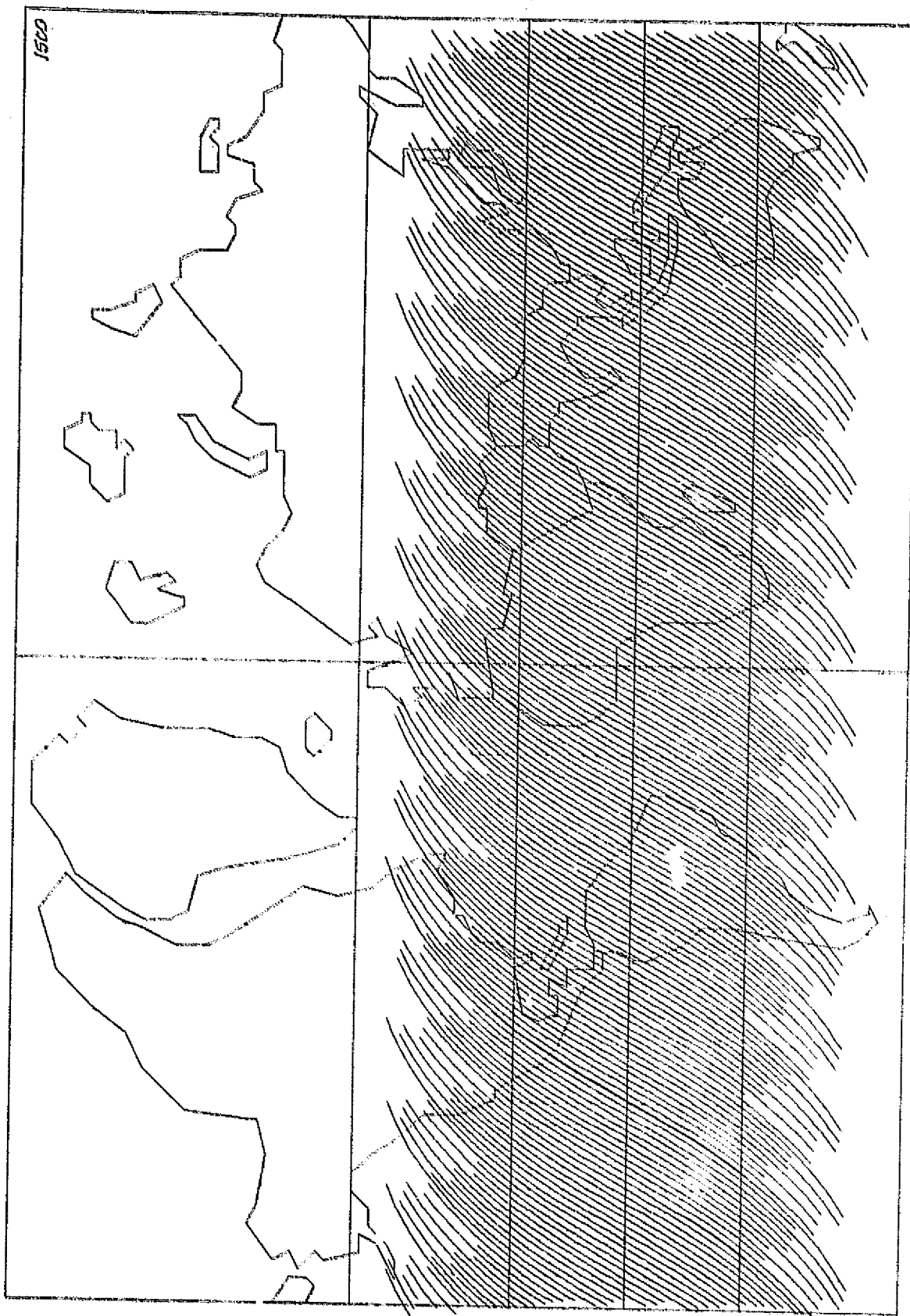
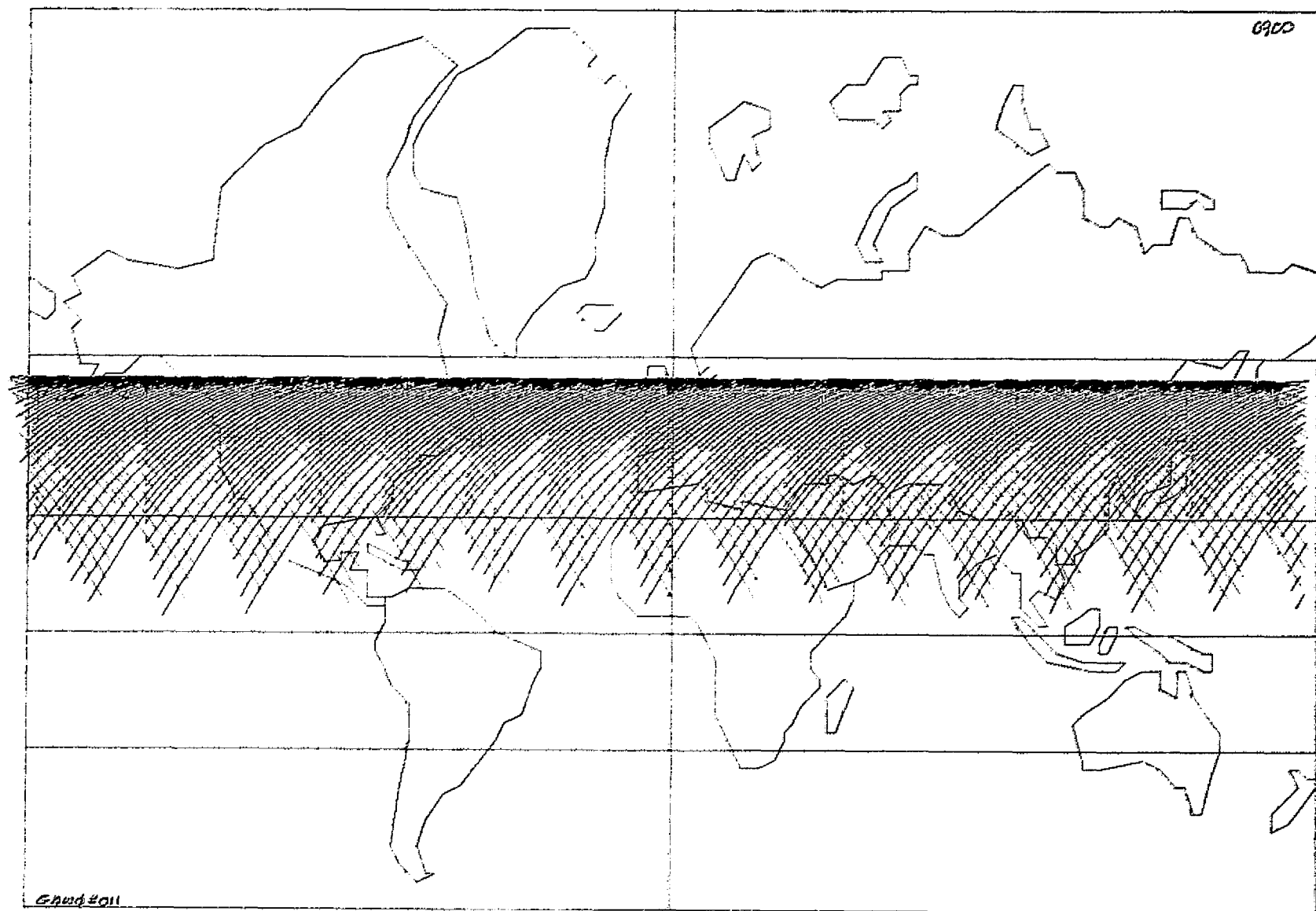


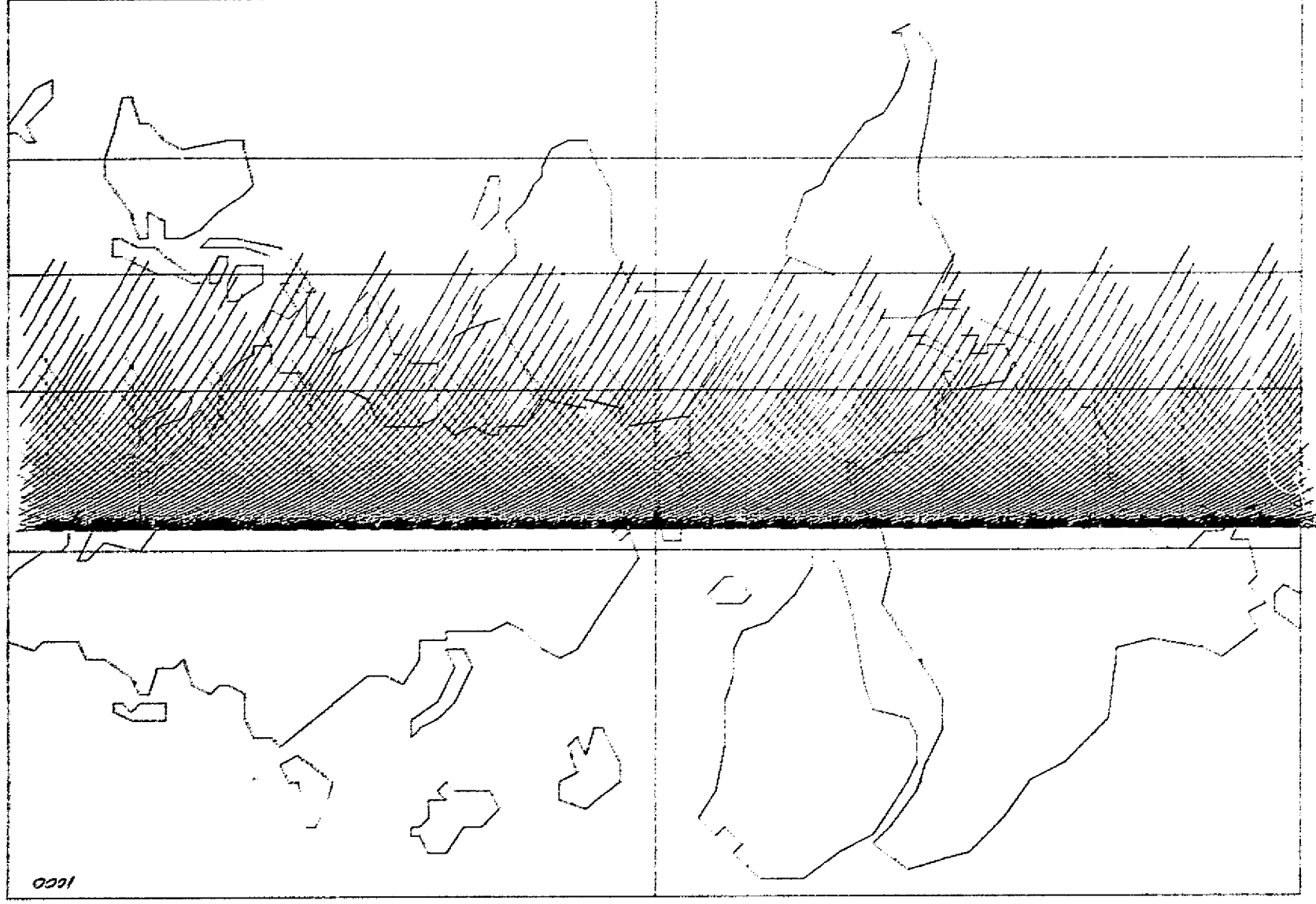
FIGURE PACK 5 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

Data:

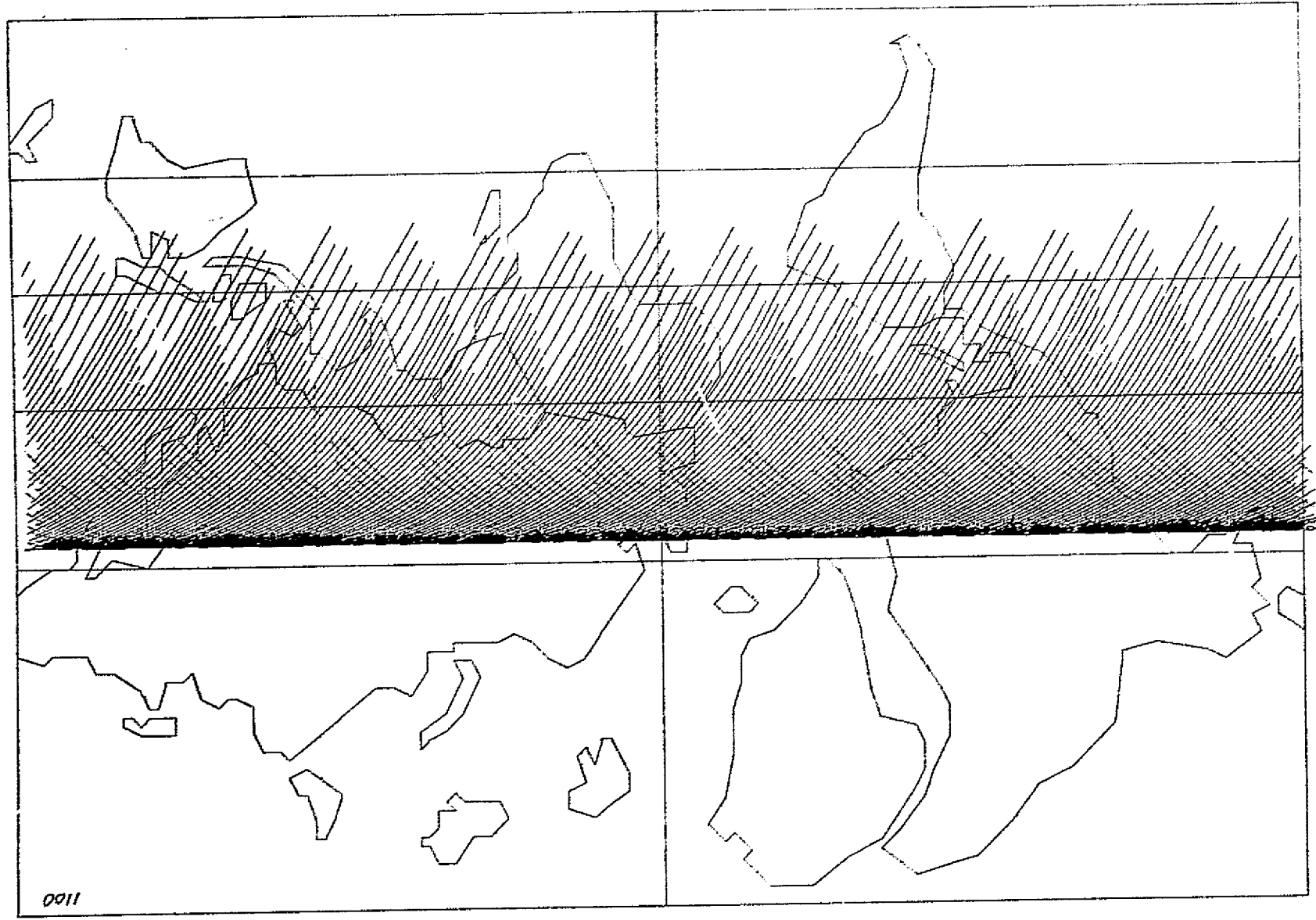
Launch site	KSC
Inclination	57 degrees
Altitude	275.9 kilometers
Launch date	1 July
Launch time	0900 to 1500 hours (hourly)



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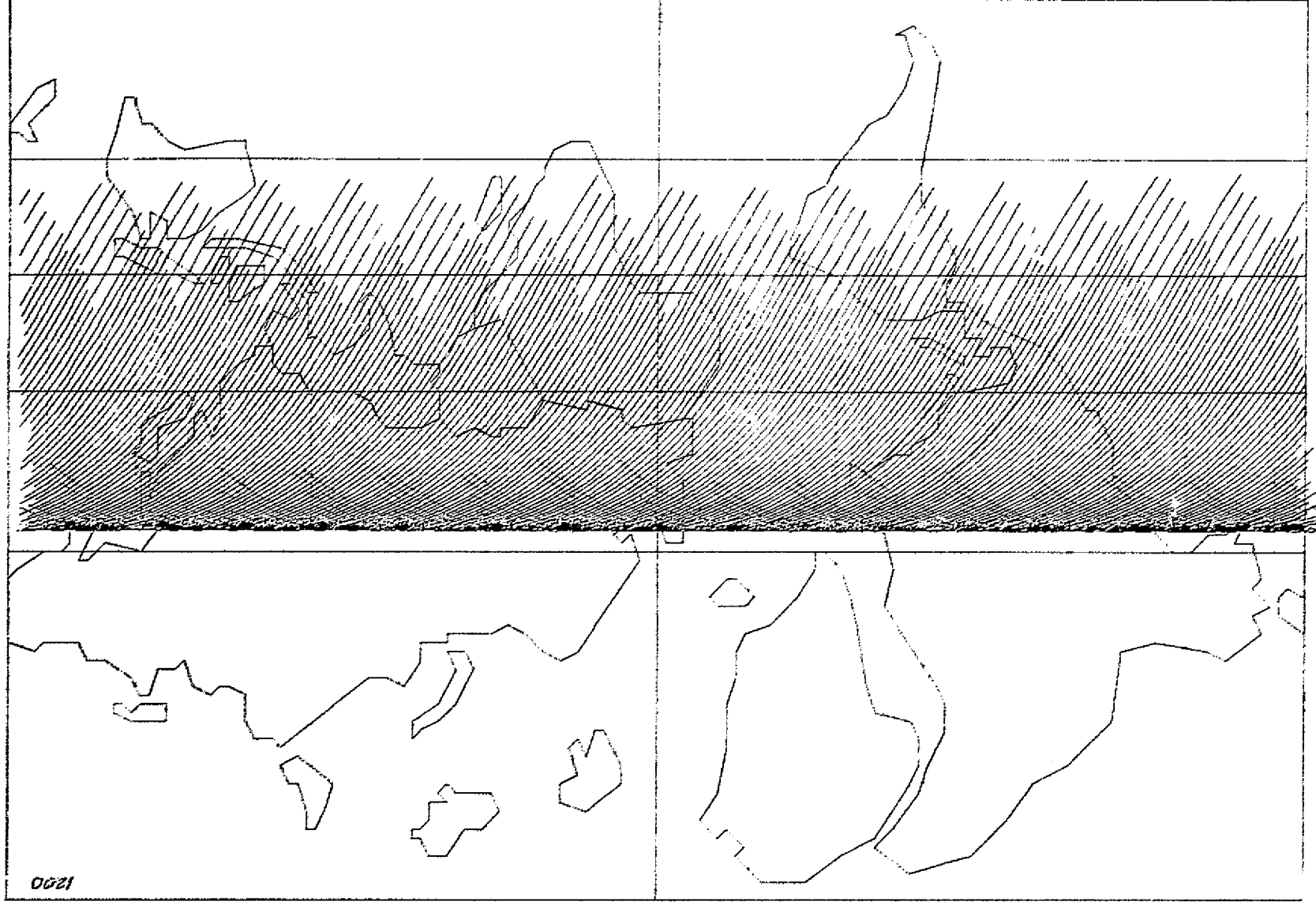
B-37

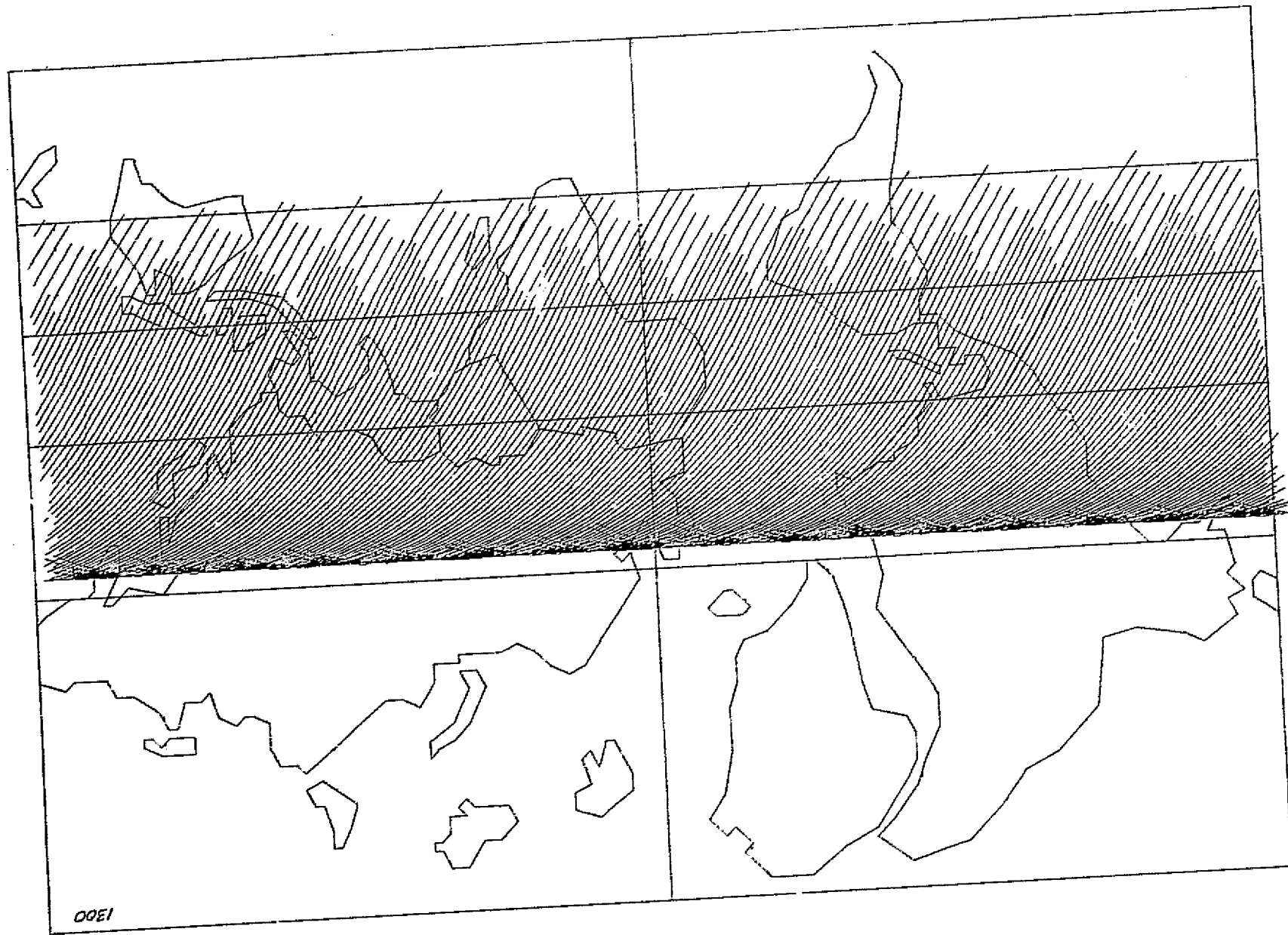


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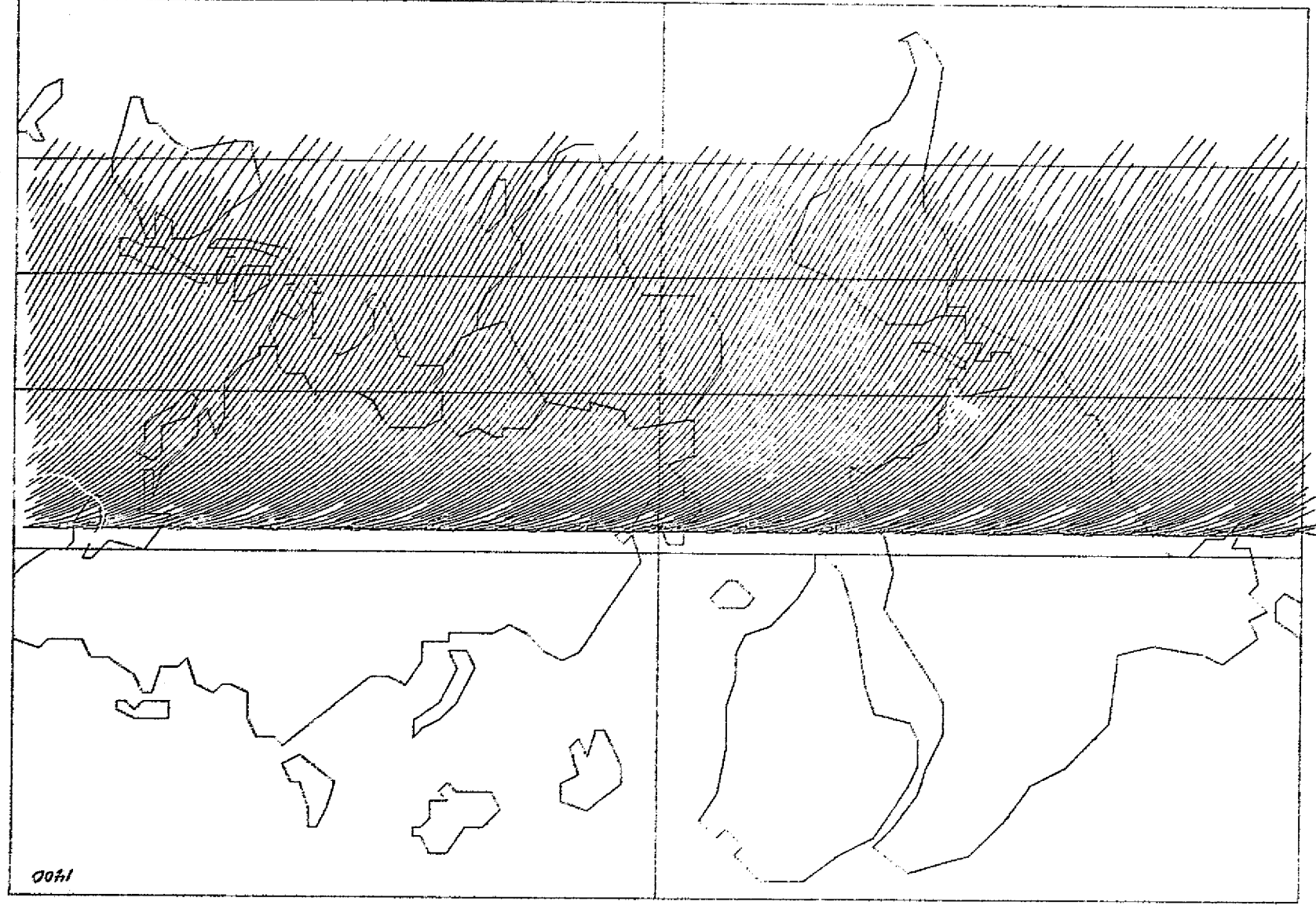
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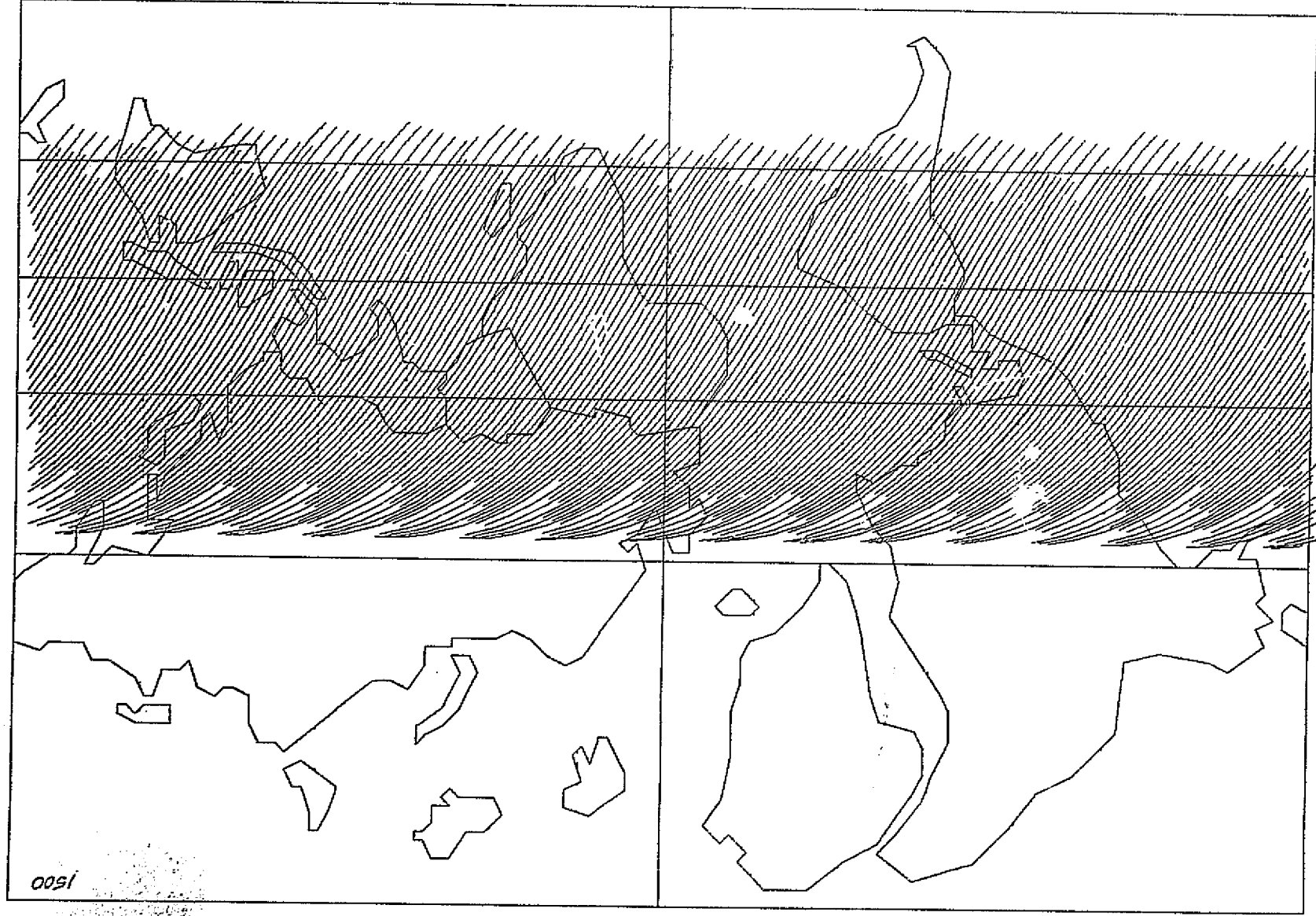
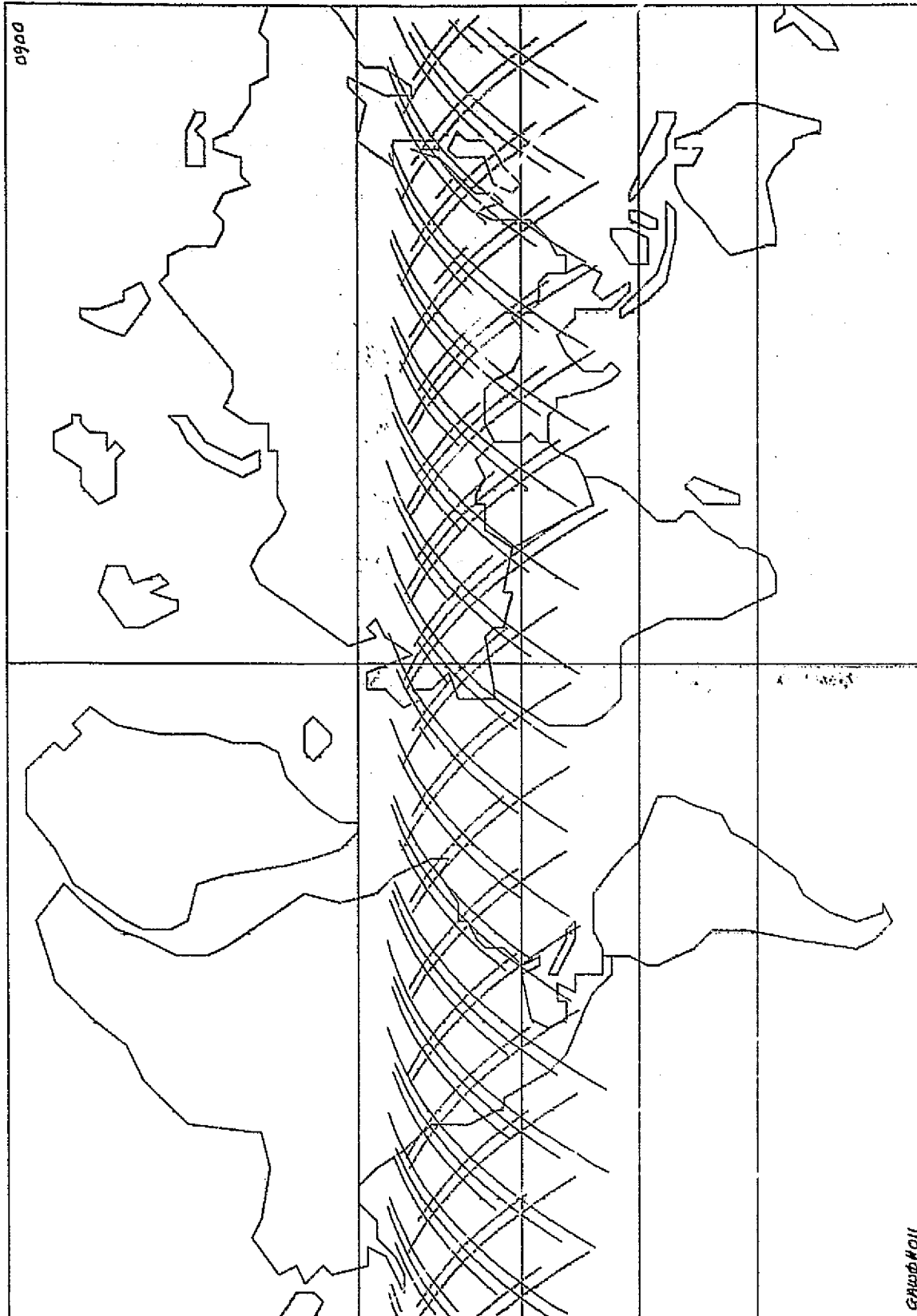


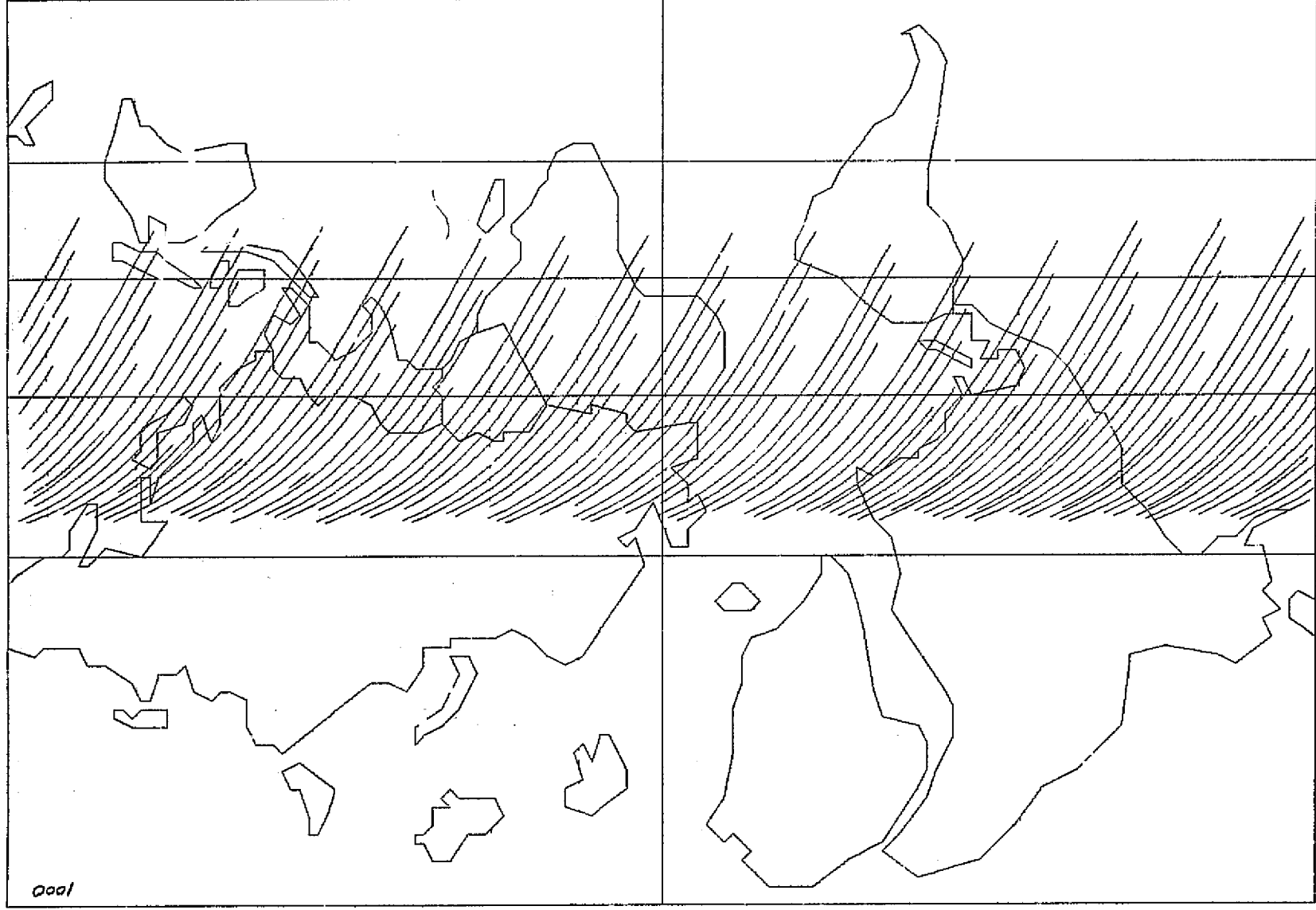
FIGURE PACK 6 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

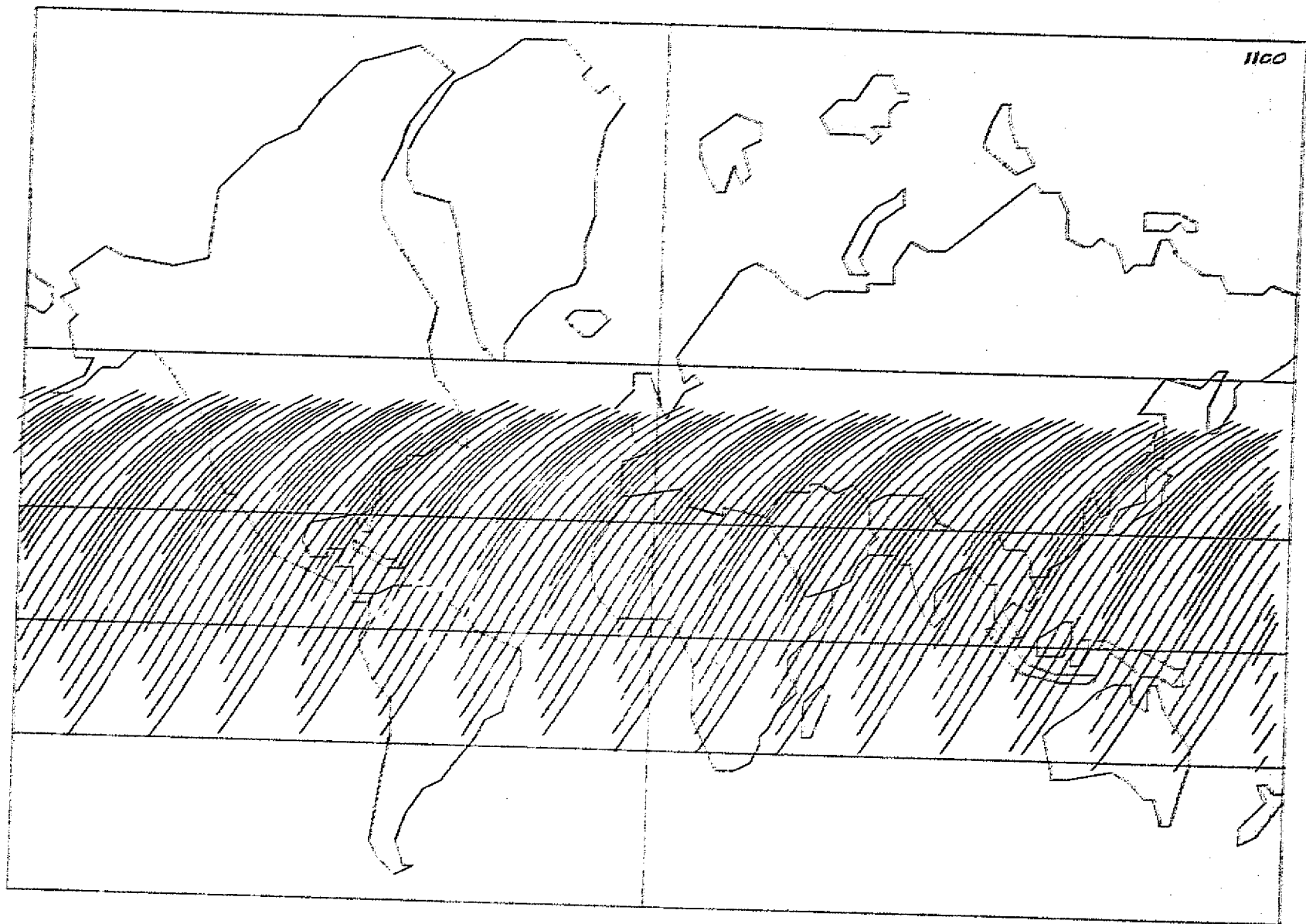
Data:

Launch site	KSC
Inclination	57 degrees
Altitude	275.9 kilometers
Launch date	1 October
Launch time	0900 to 1500 hours (hourly)

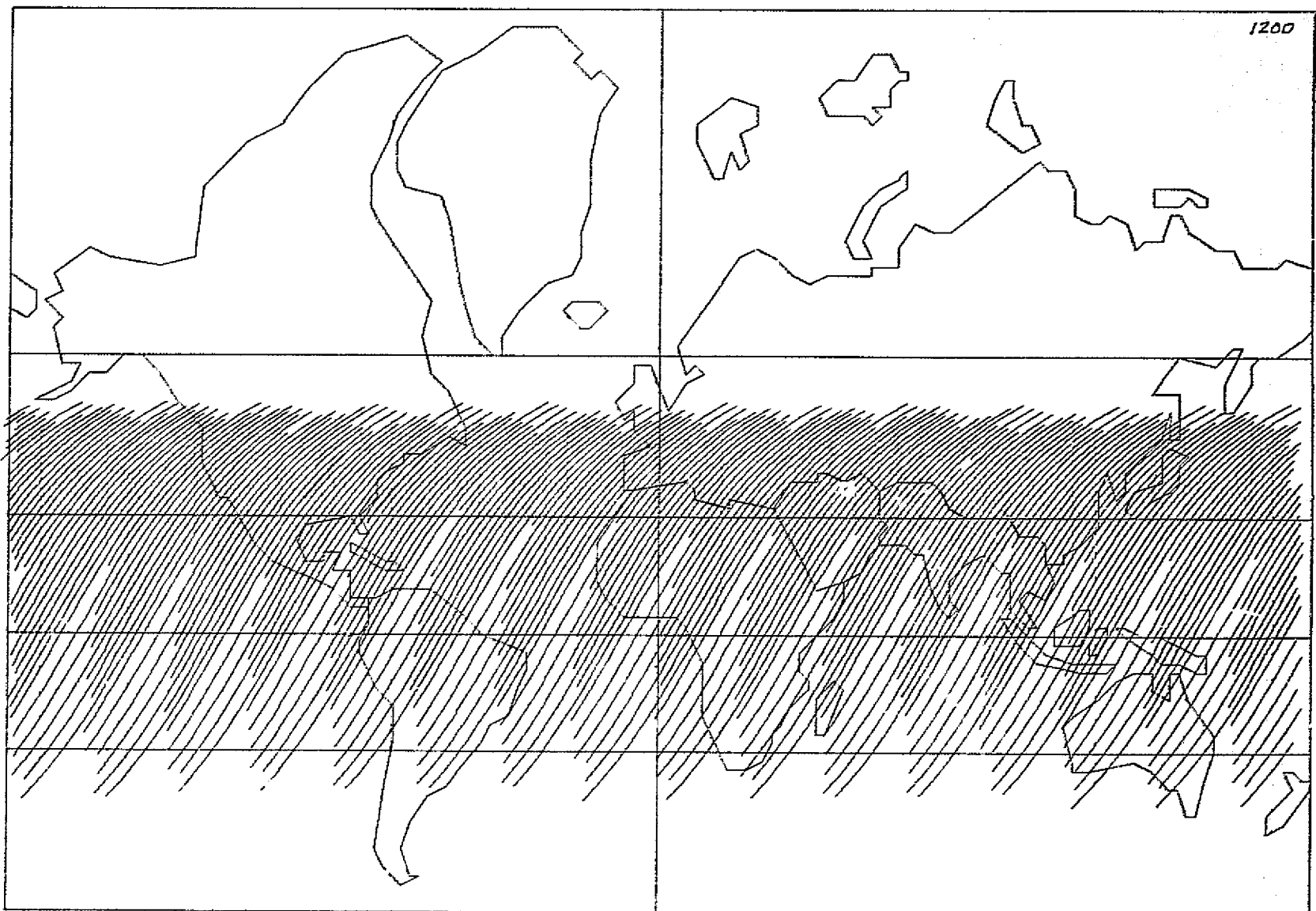


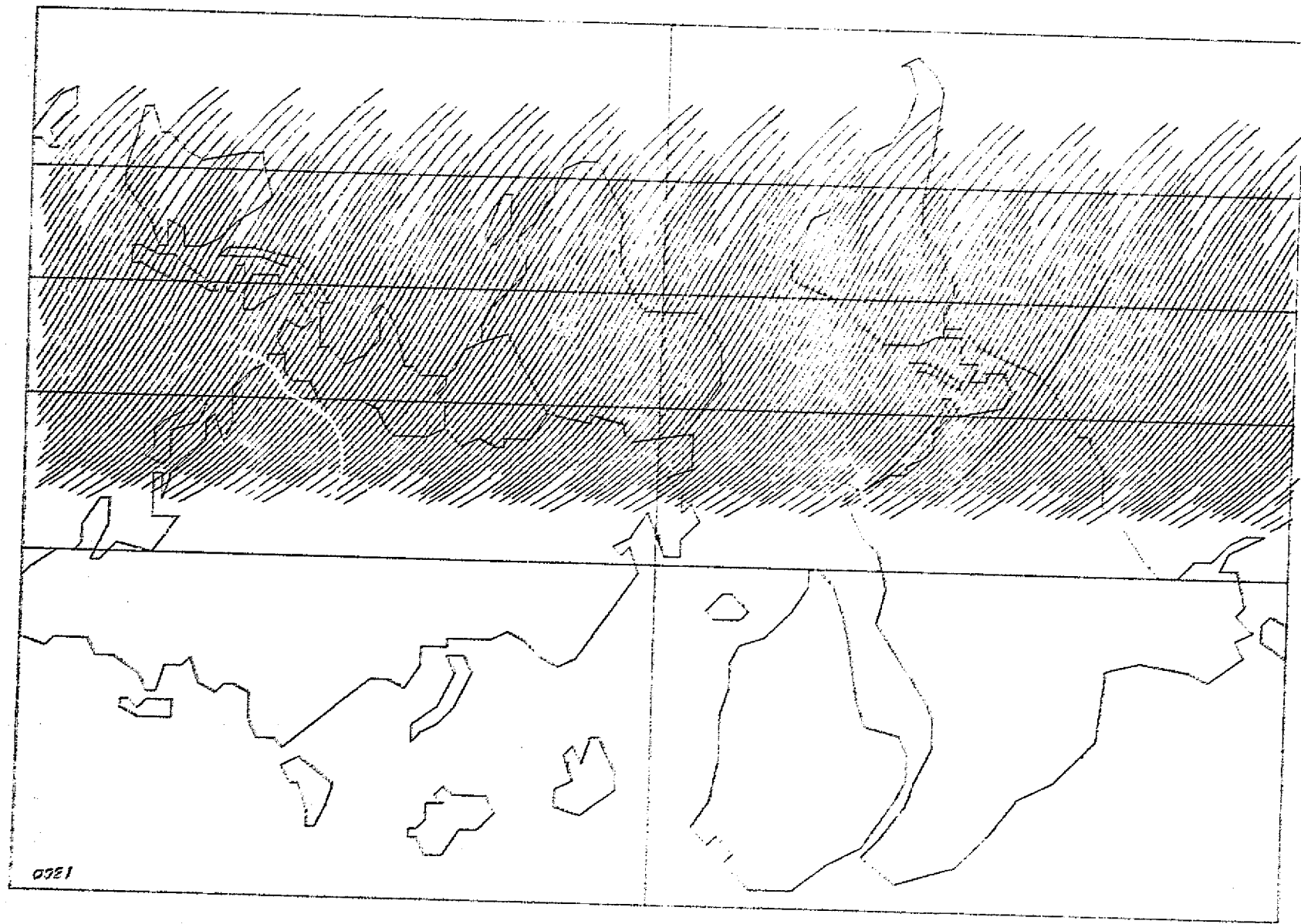
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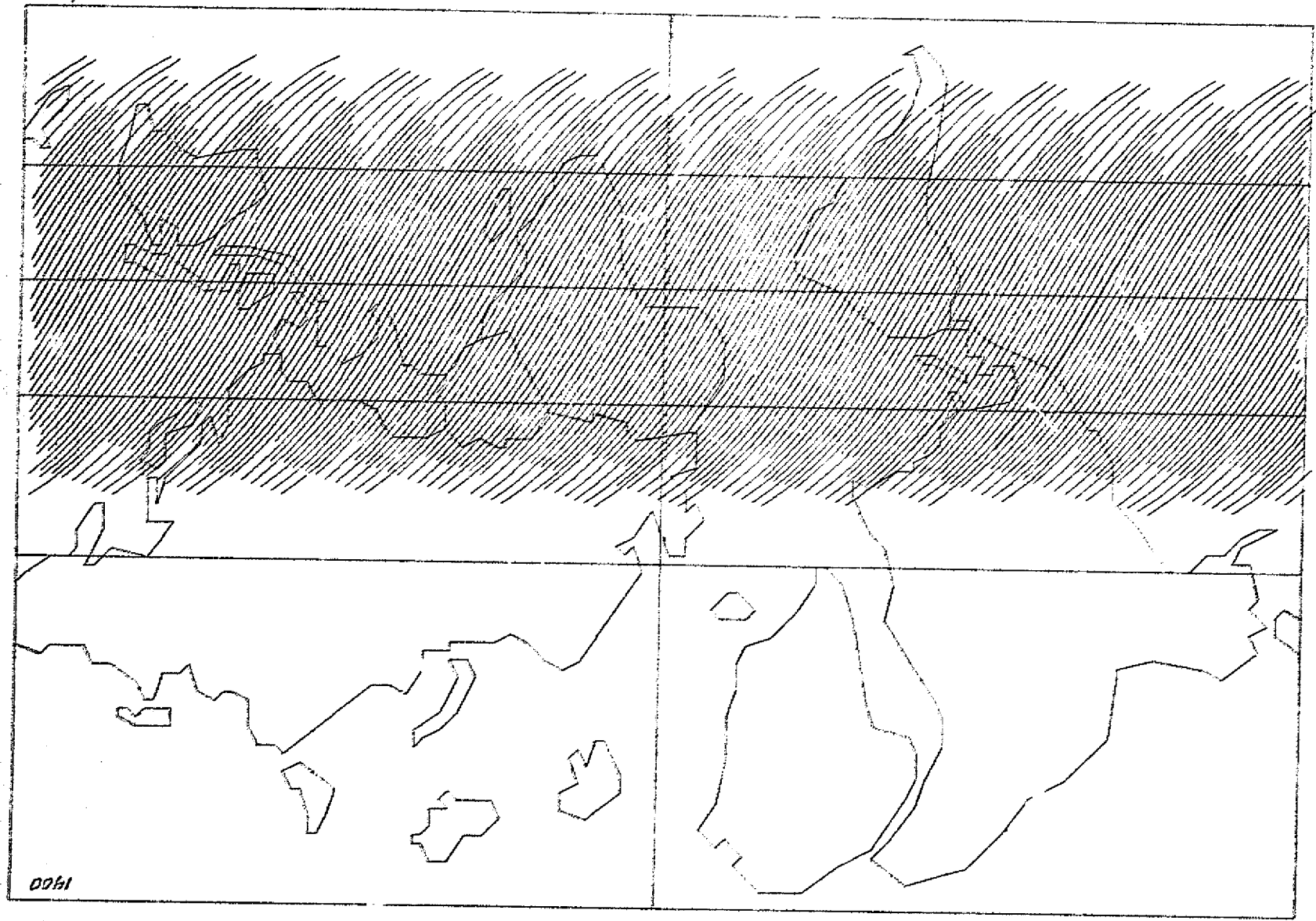


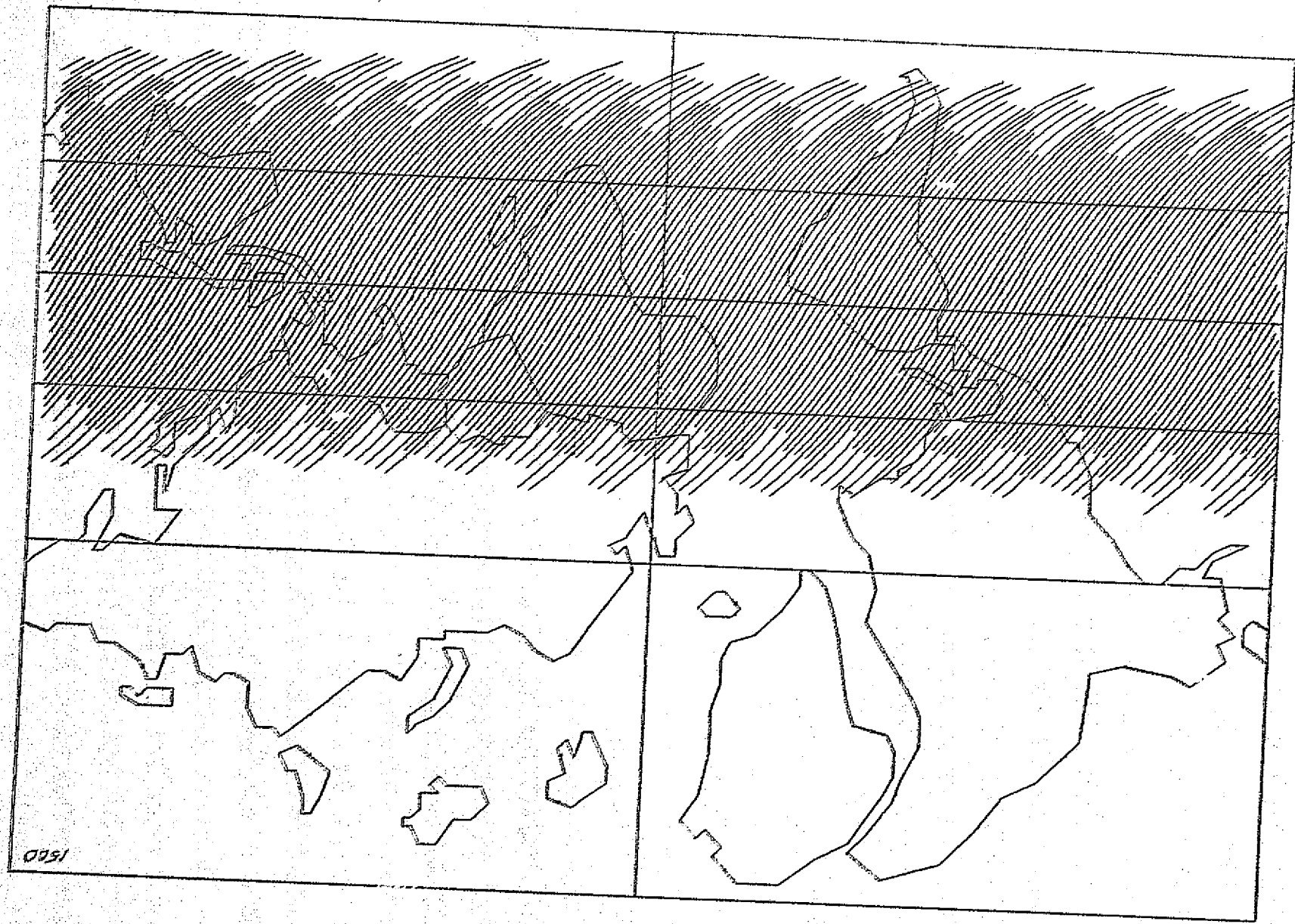
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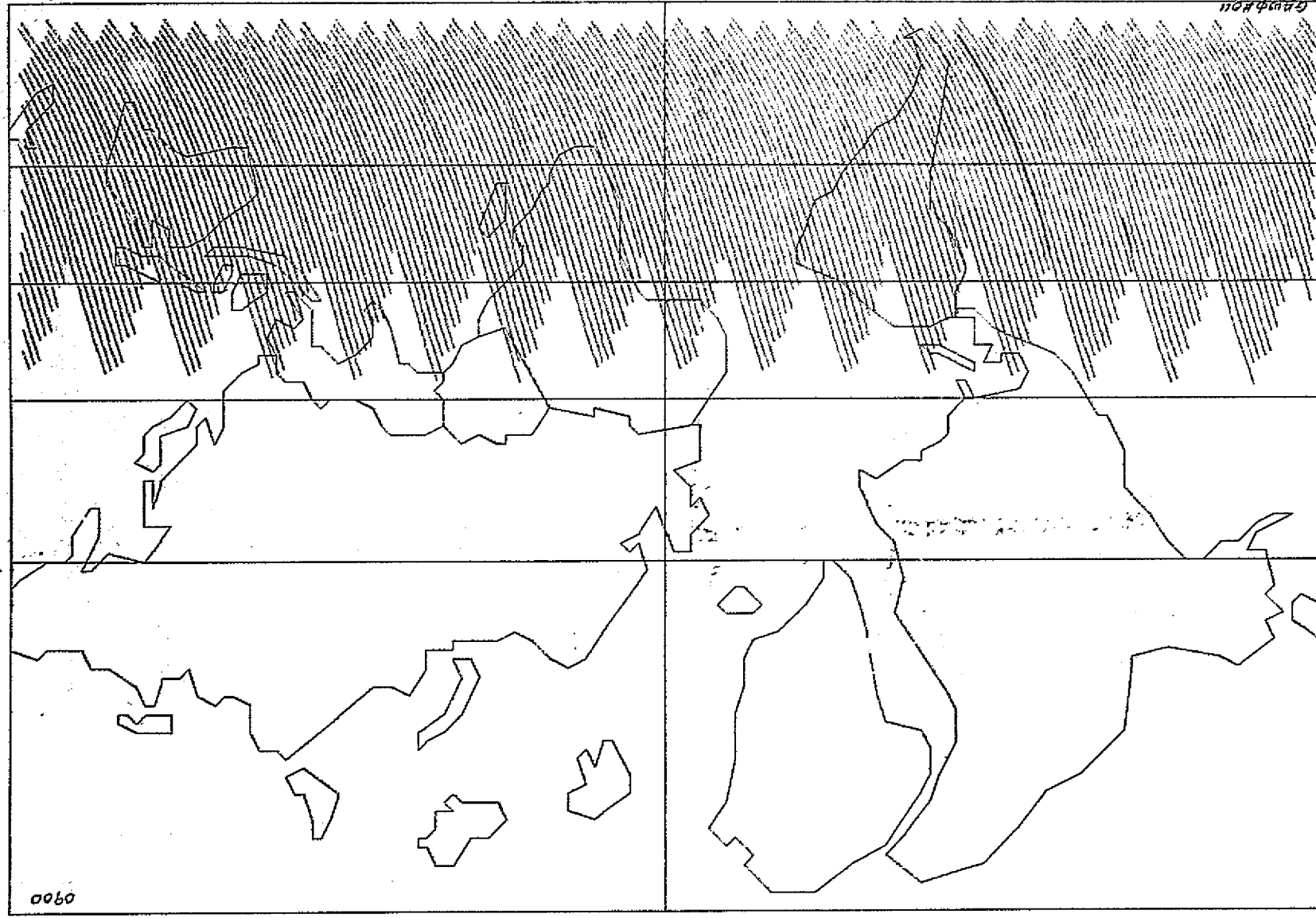


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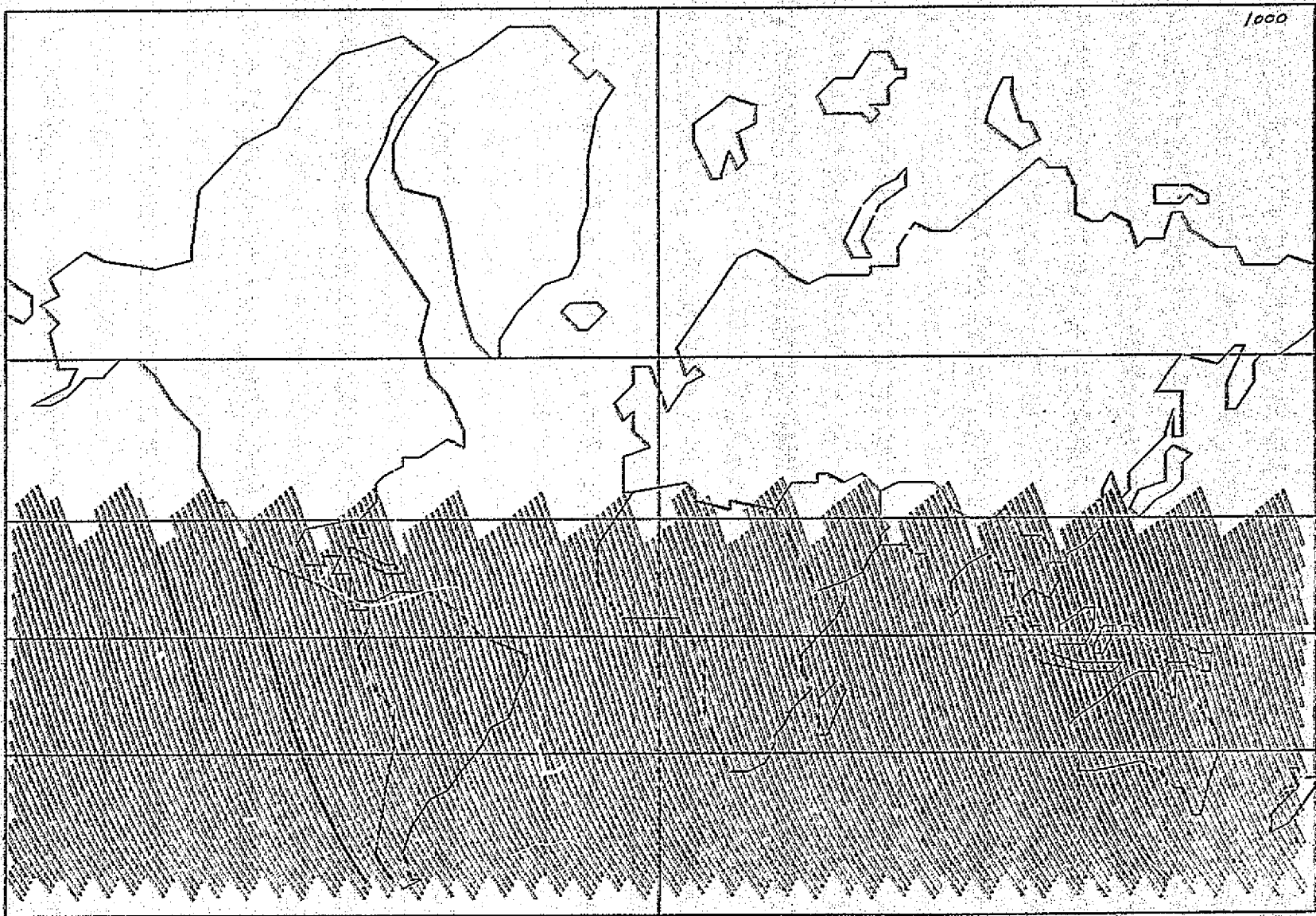
FIGURE PACK 7 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

Data:

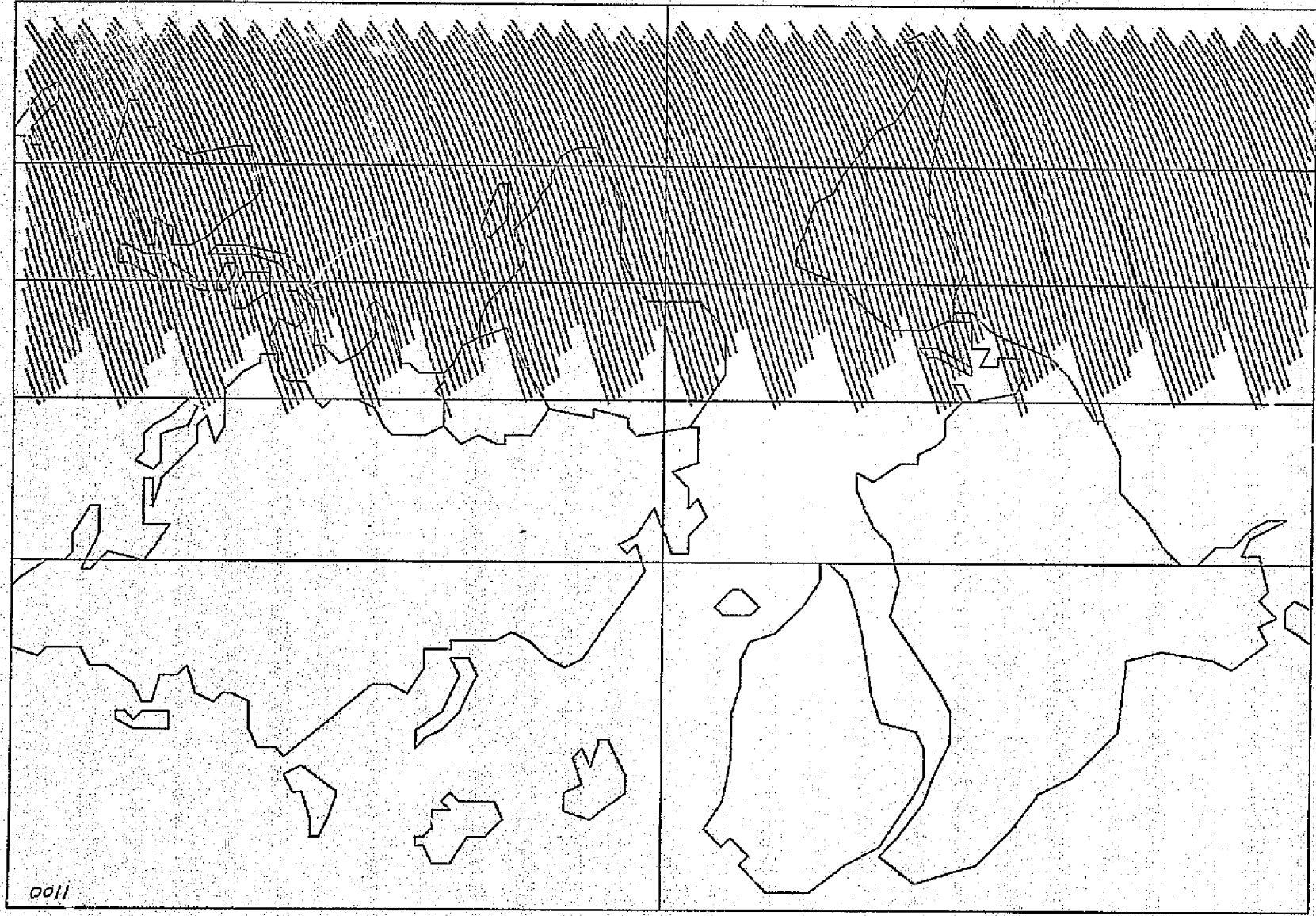
Launch site	VAFB
Inclination	70 degrees
Altitude	269.6 kilometers
Launch date	1 January
Launch time	0900 to 1500 hours (hourly)



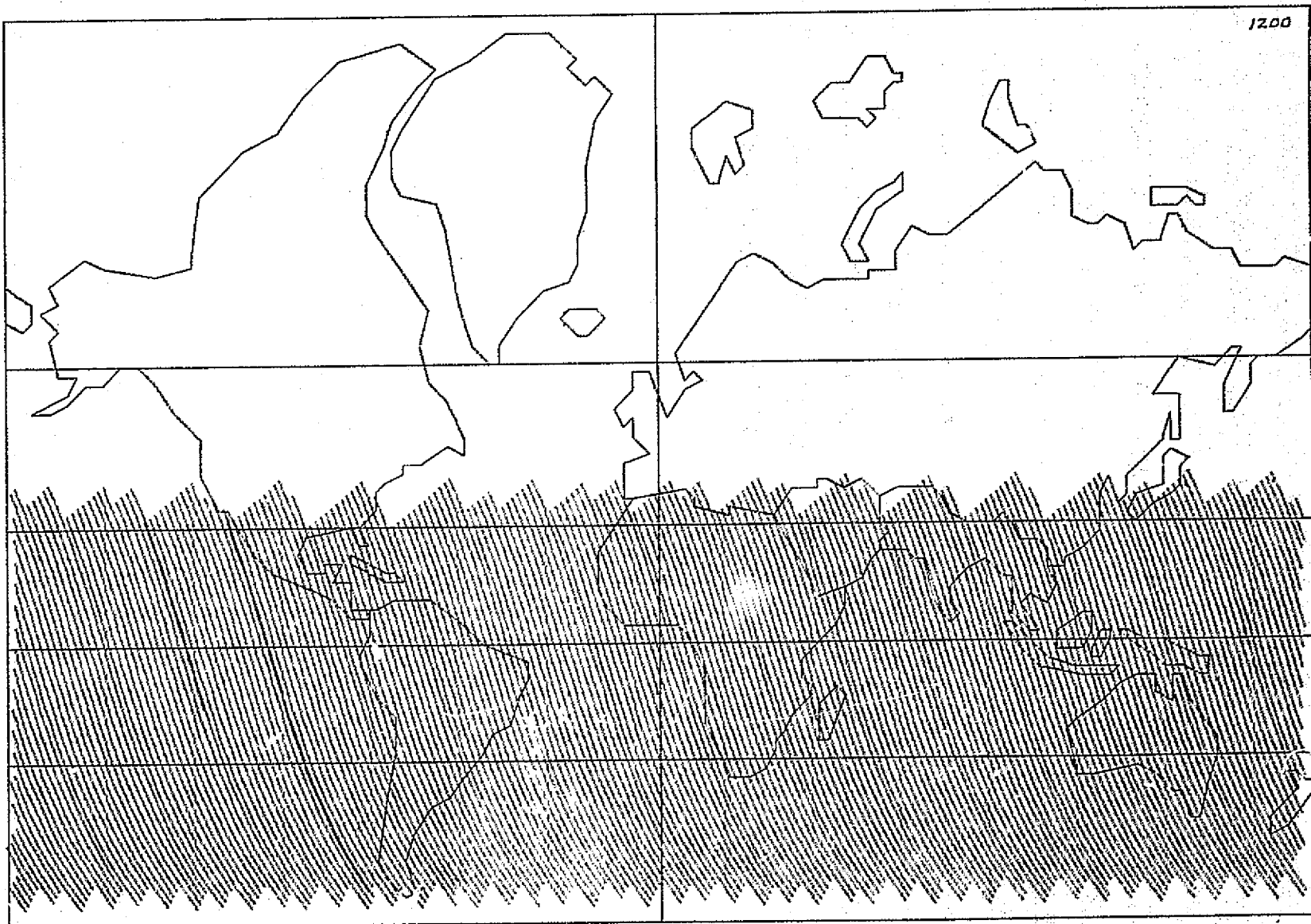
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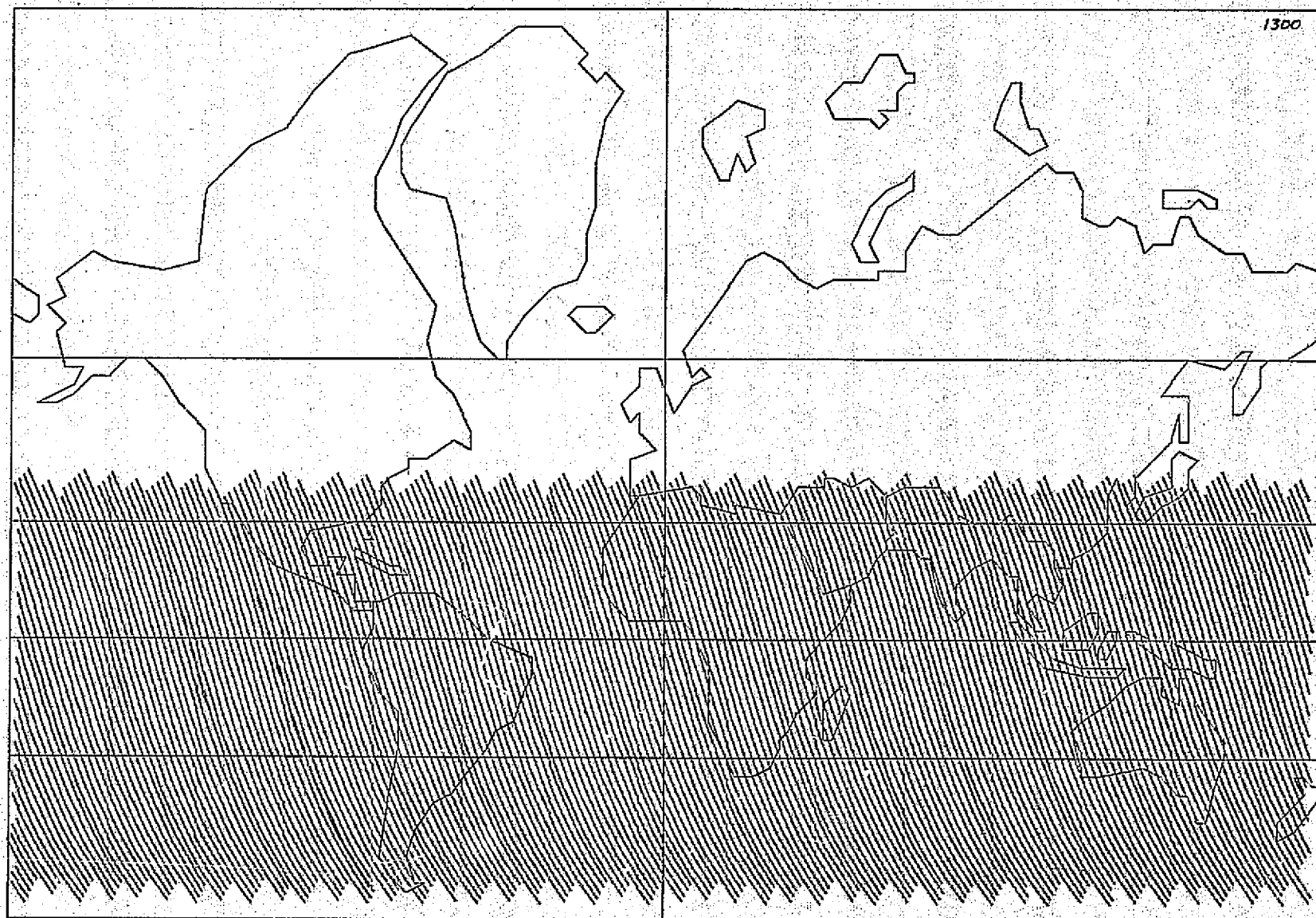


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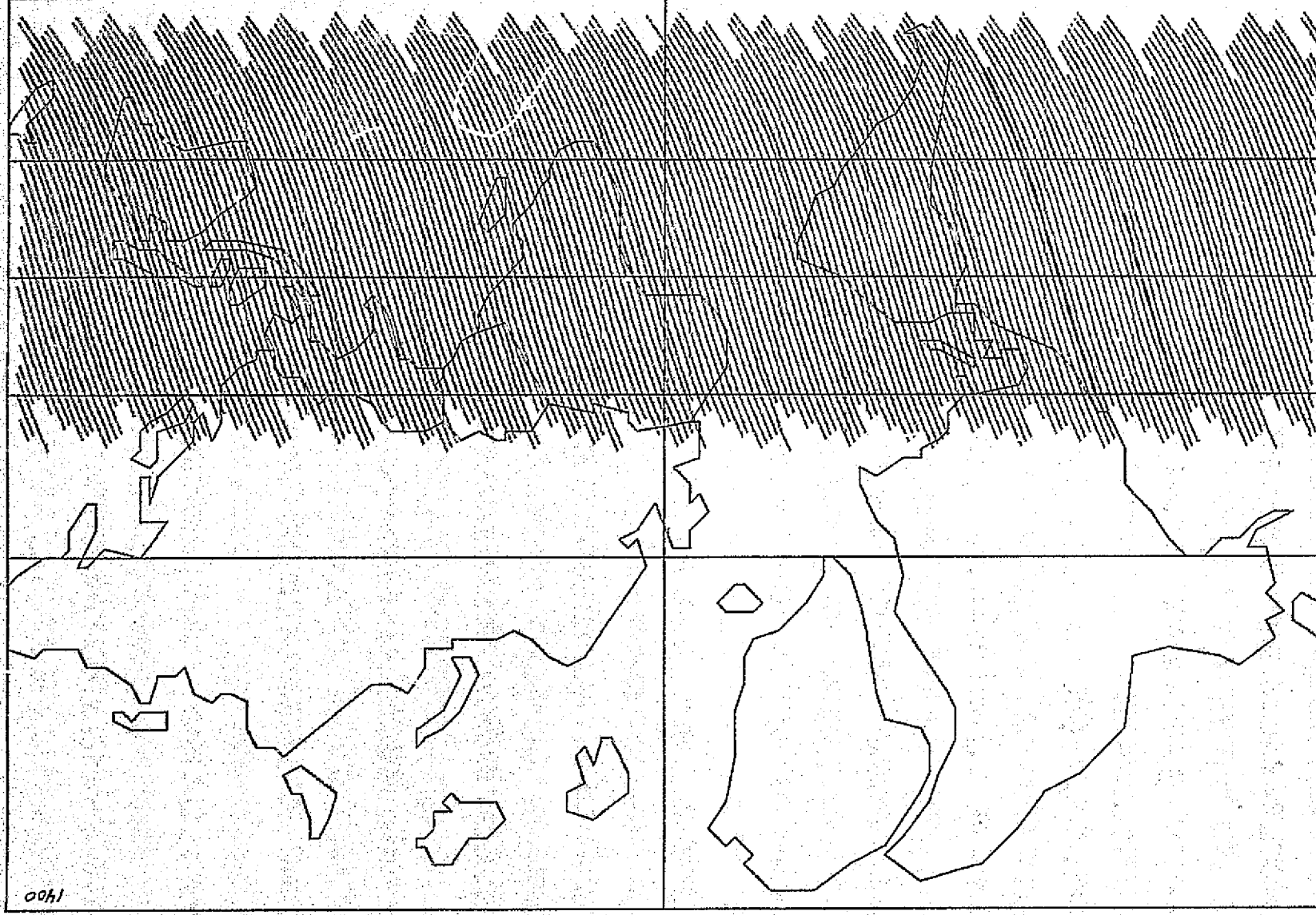


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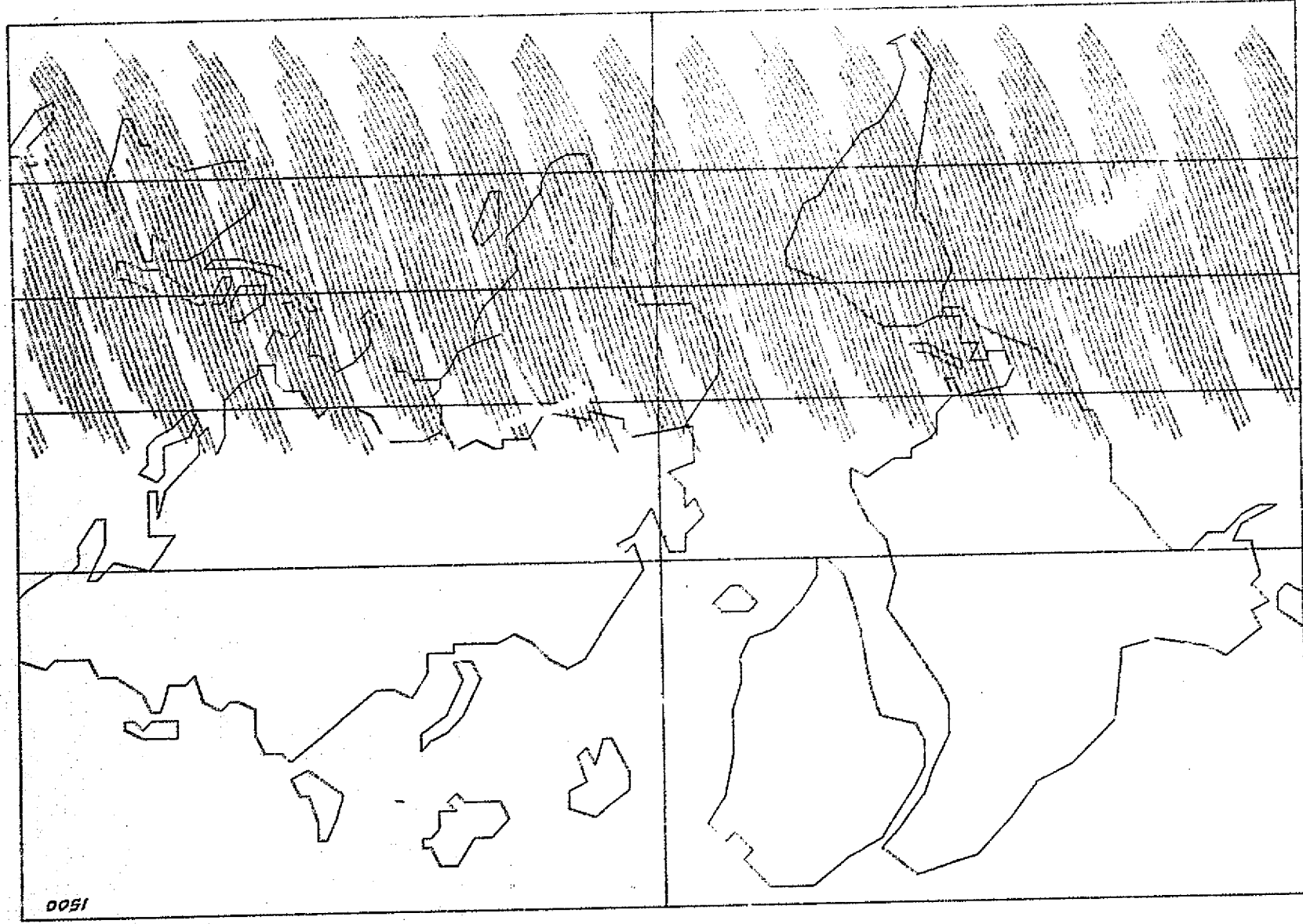
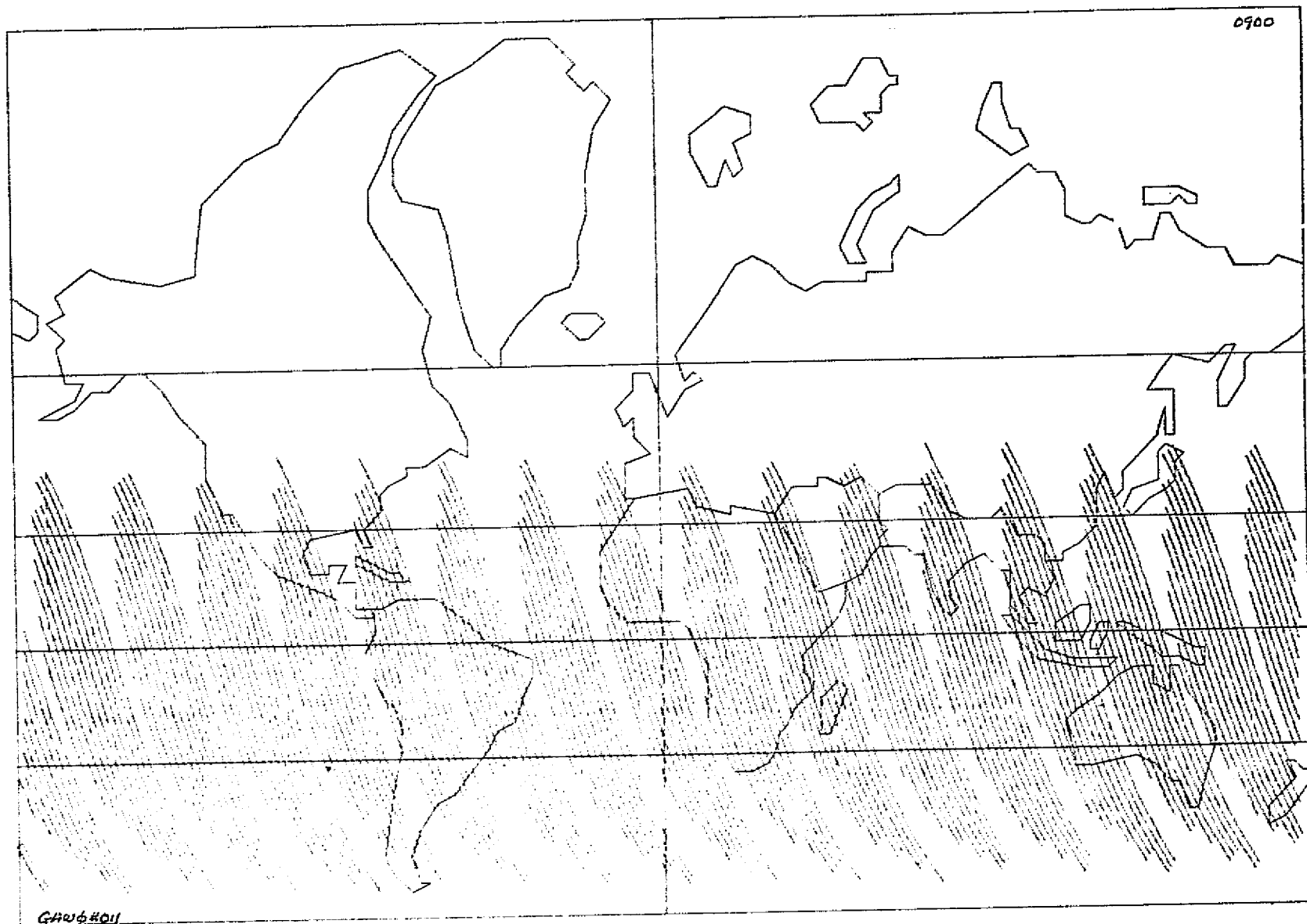
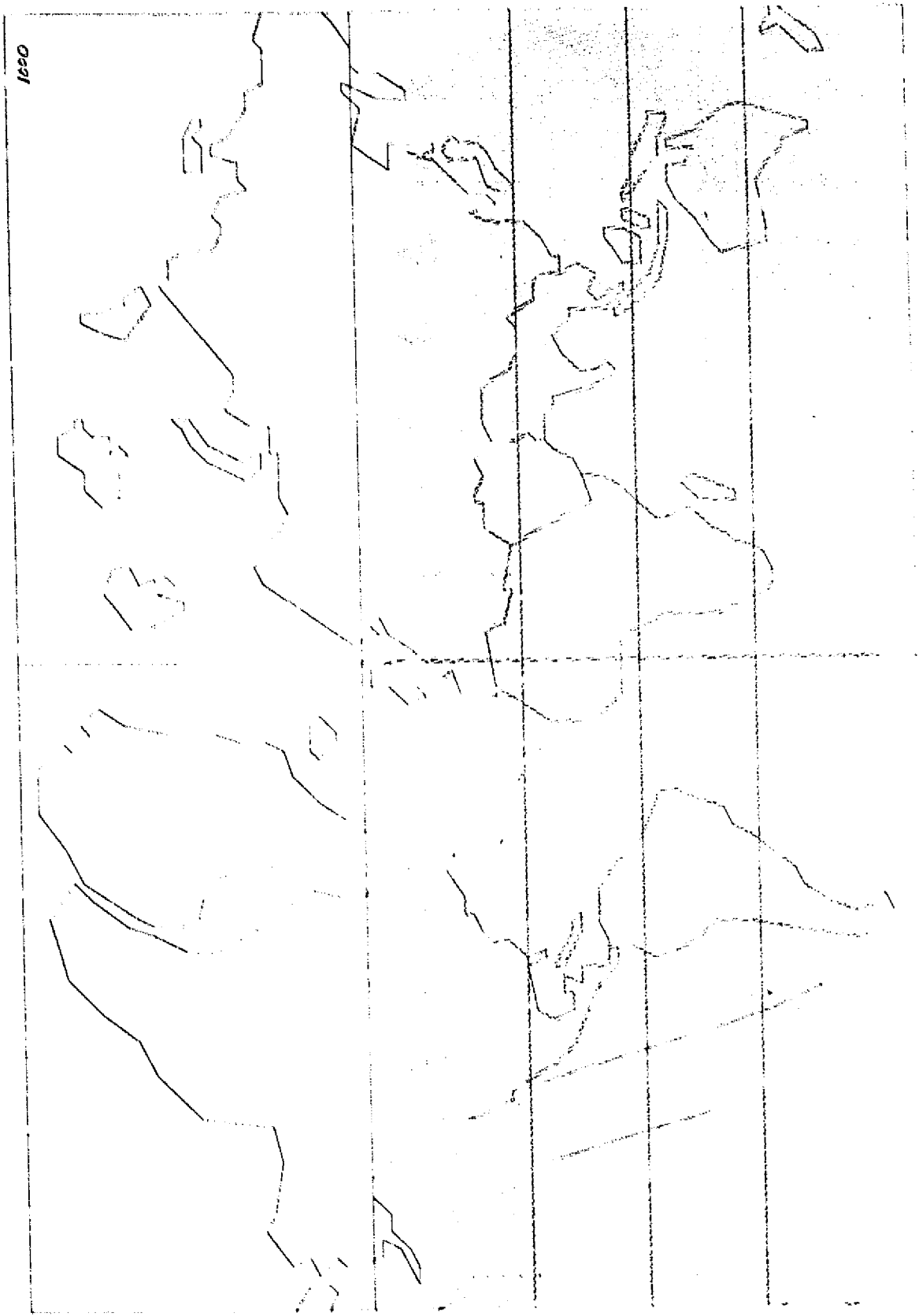


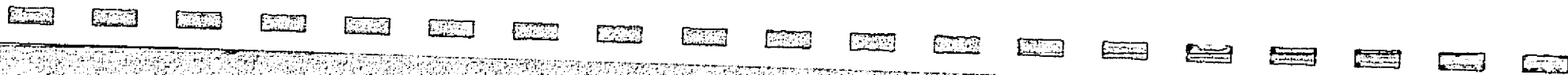
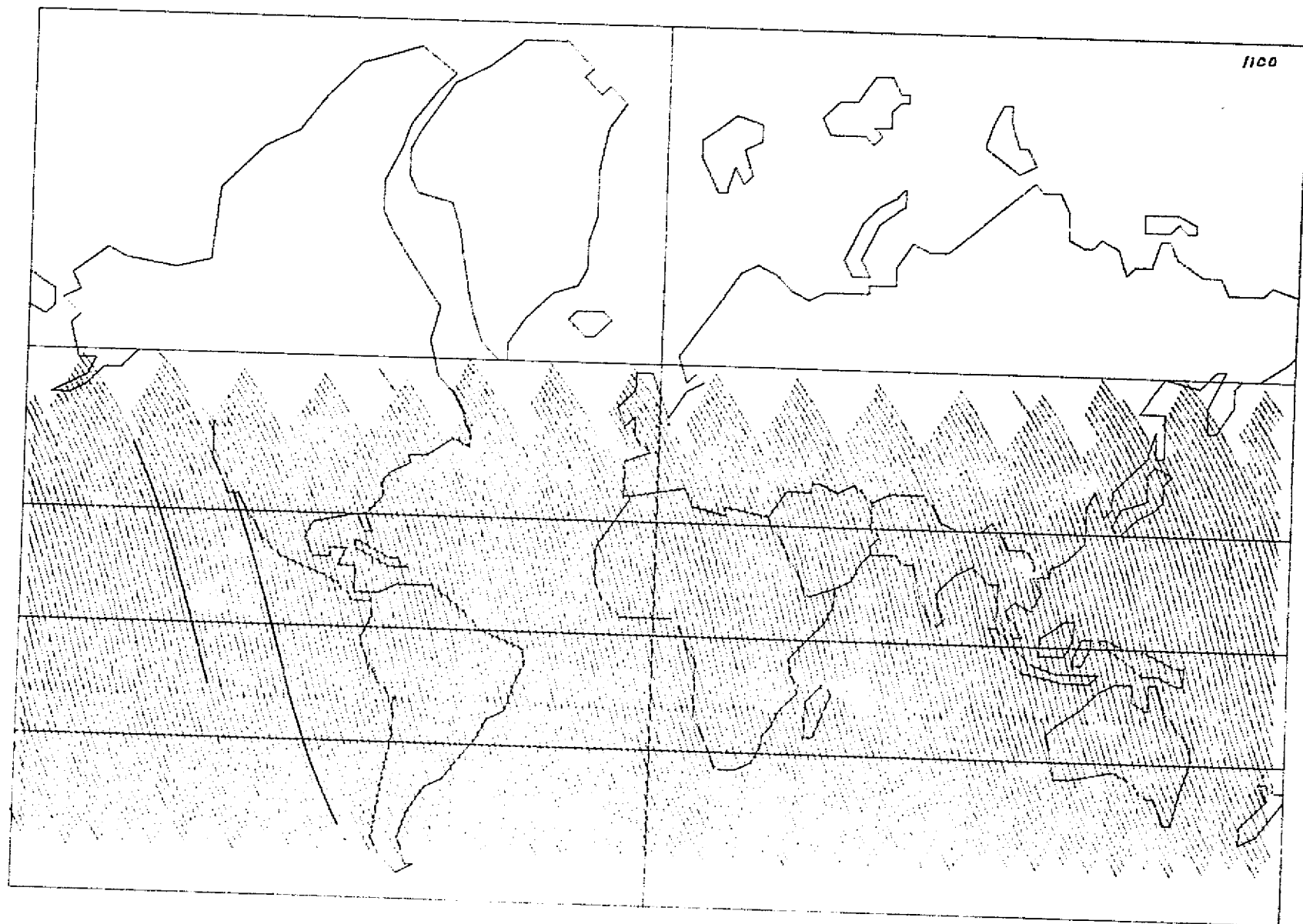
FIGURE PACK 8 -- LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

Data:

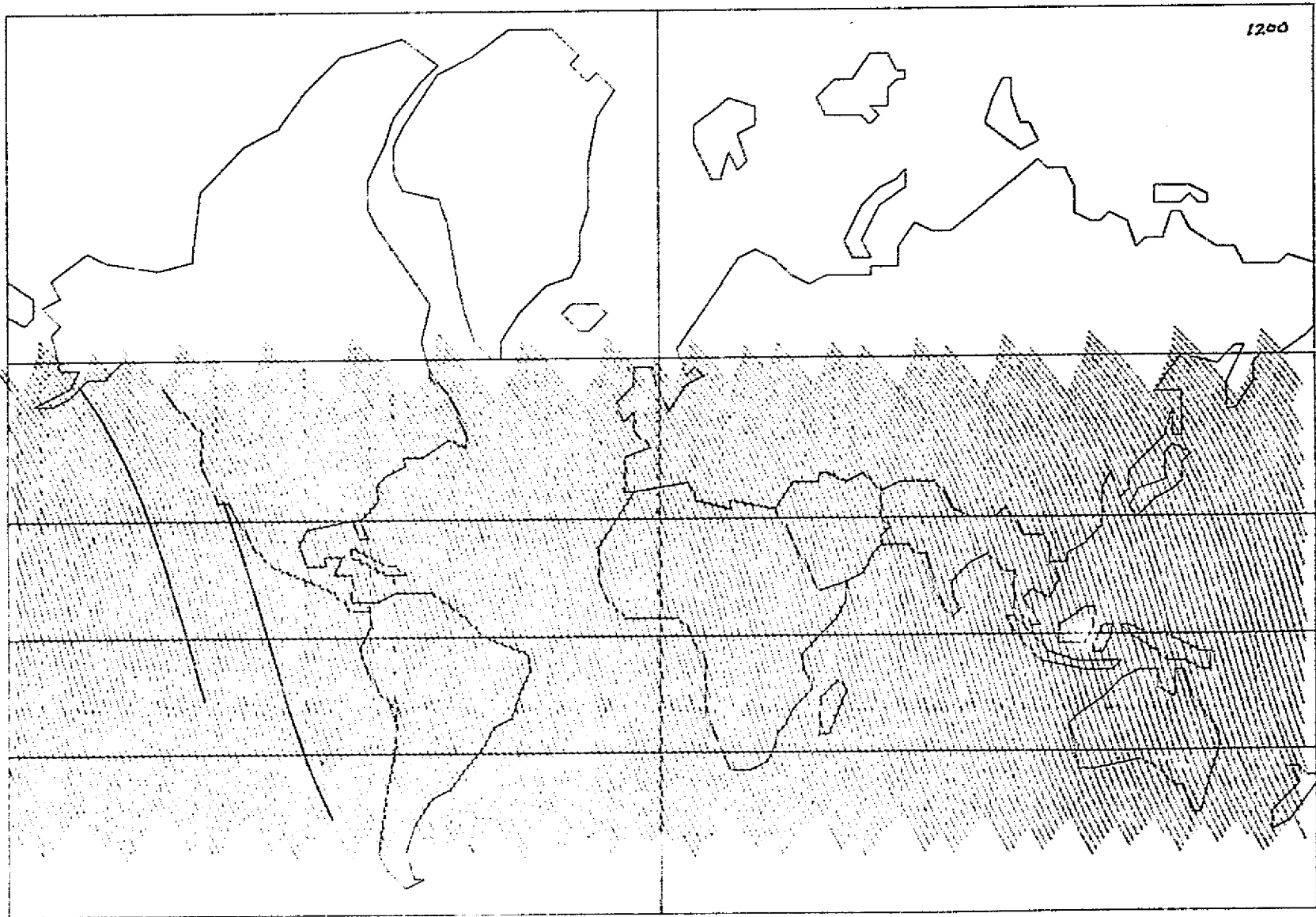
Launch site	VAFB
Inclination	70 degrees
Altitude	269.6 kilometers
Launch date	1 April
Launch time	0900 to 1500 hours (hourly)



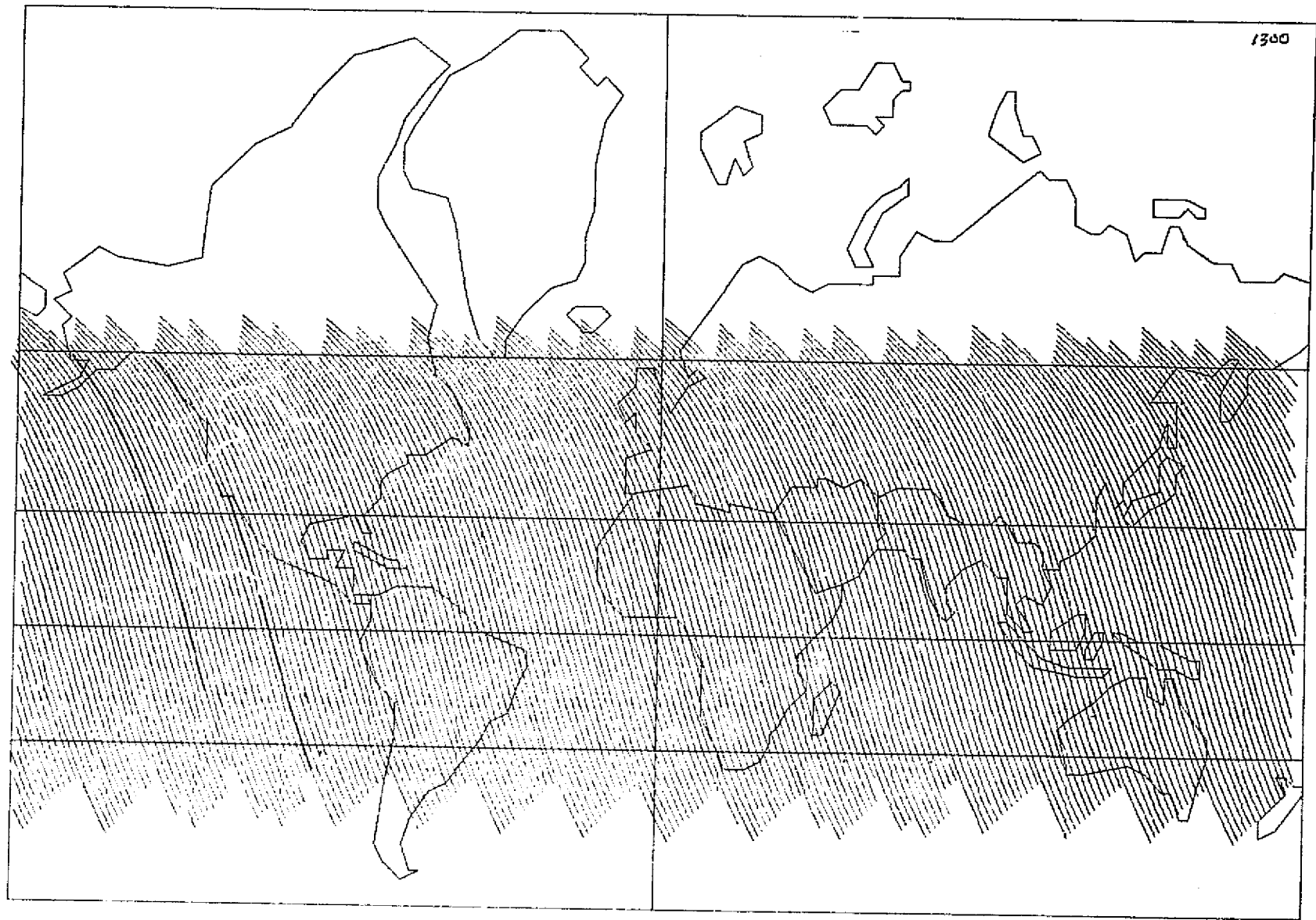




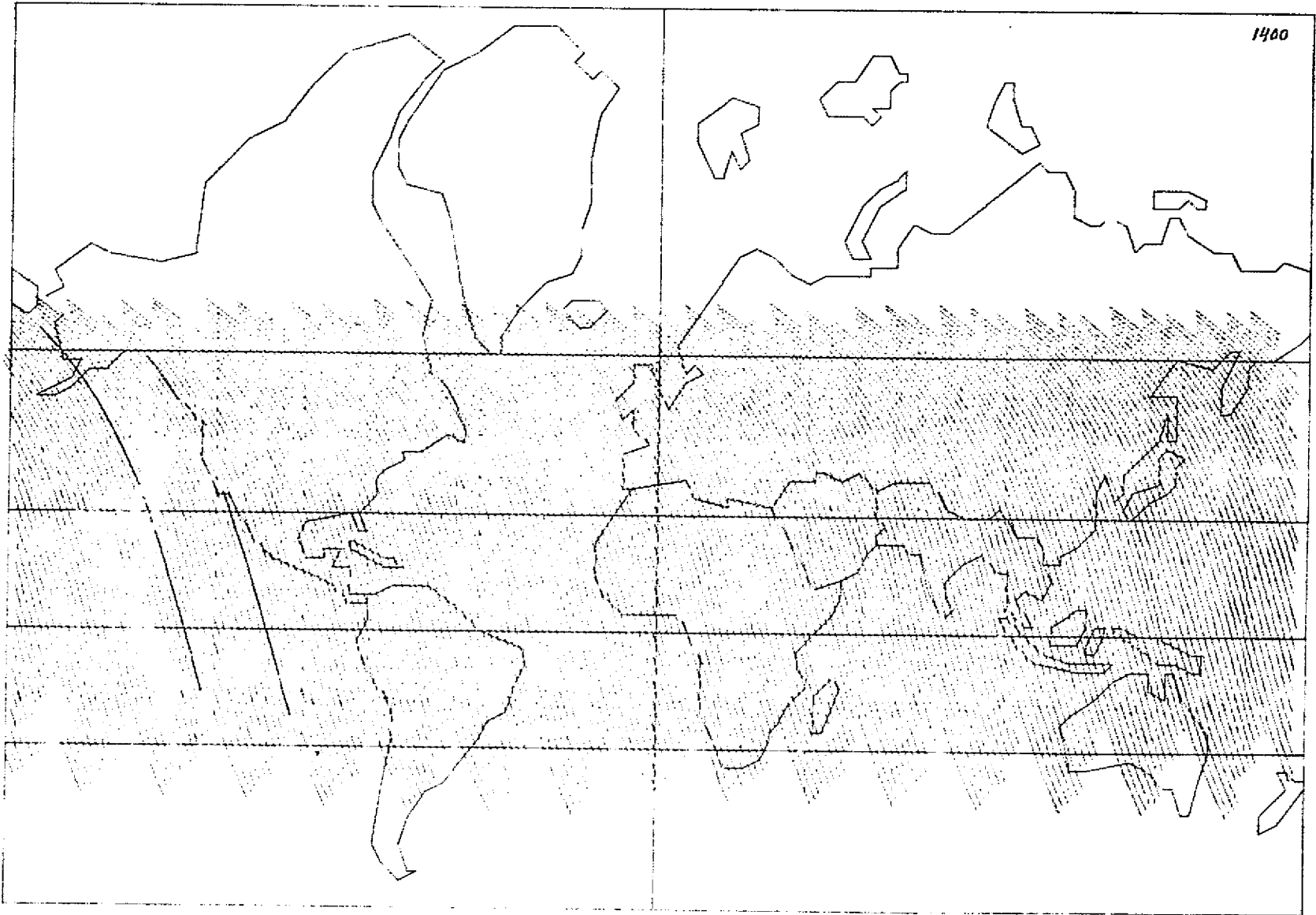
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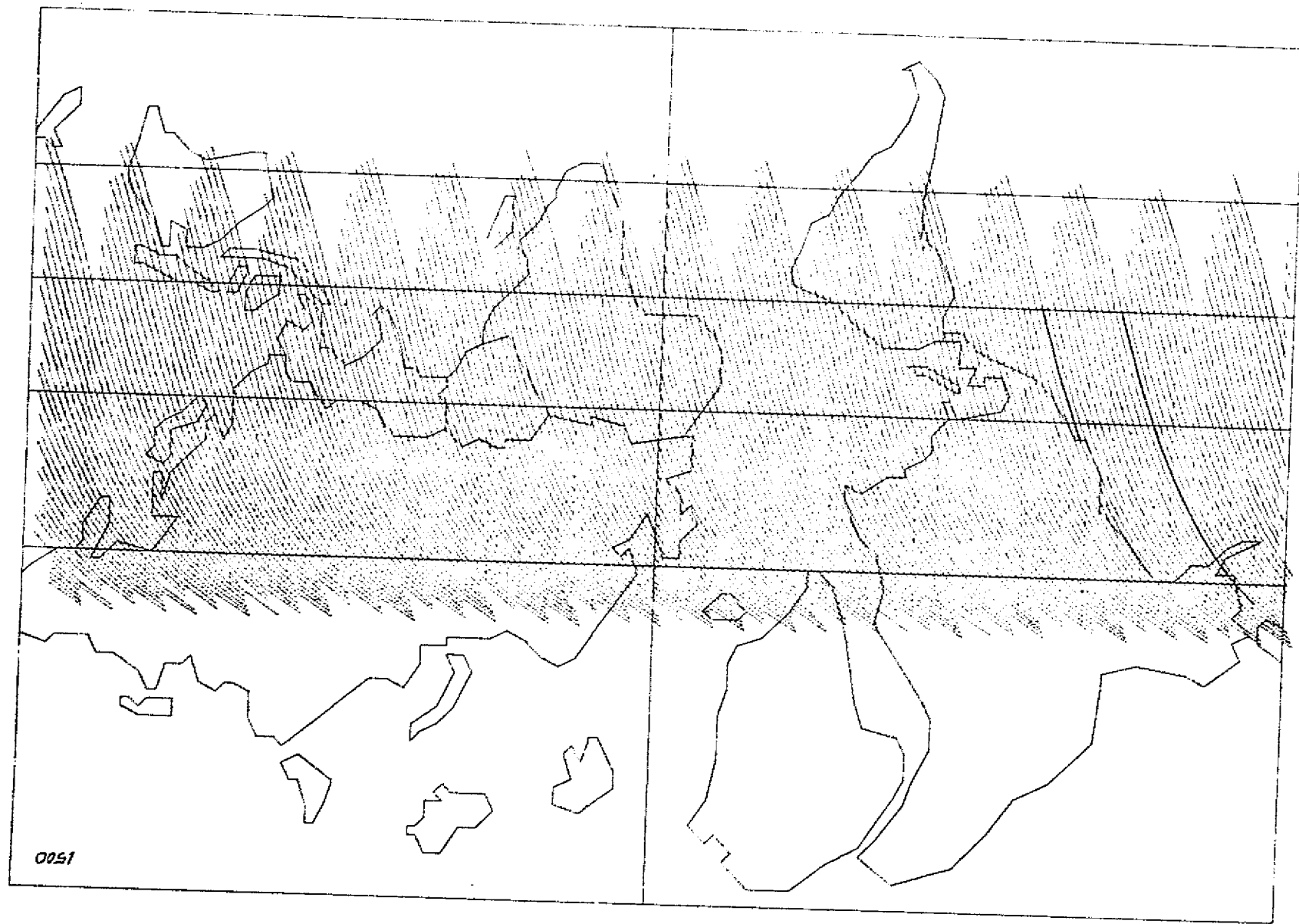
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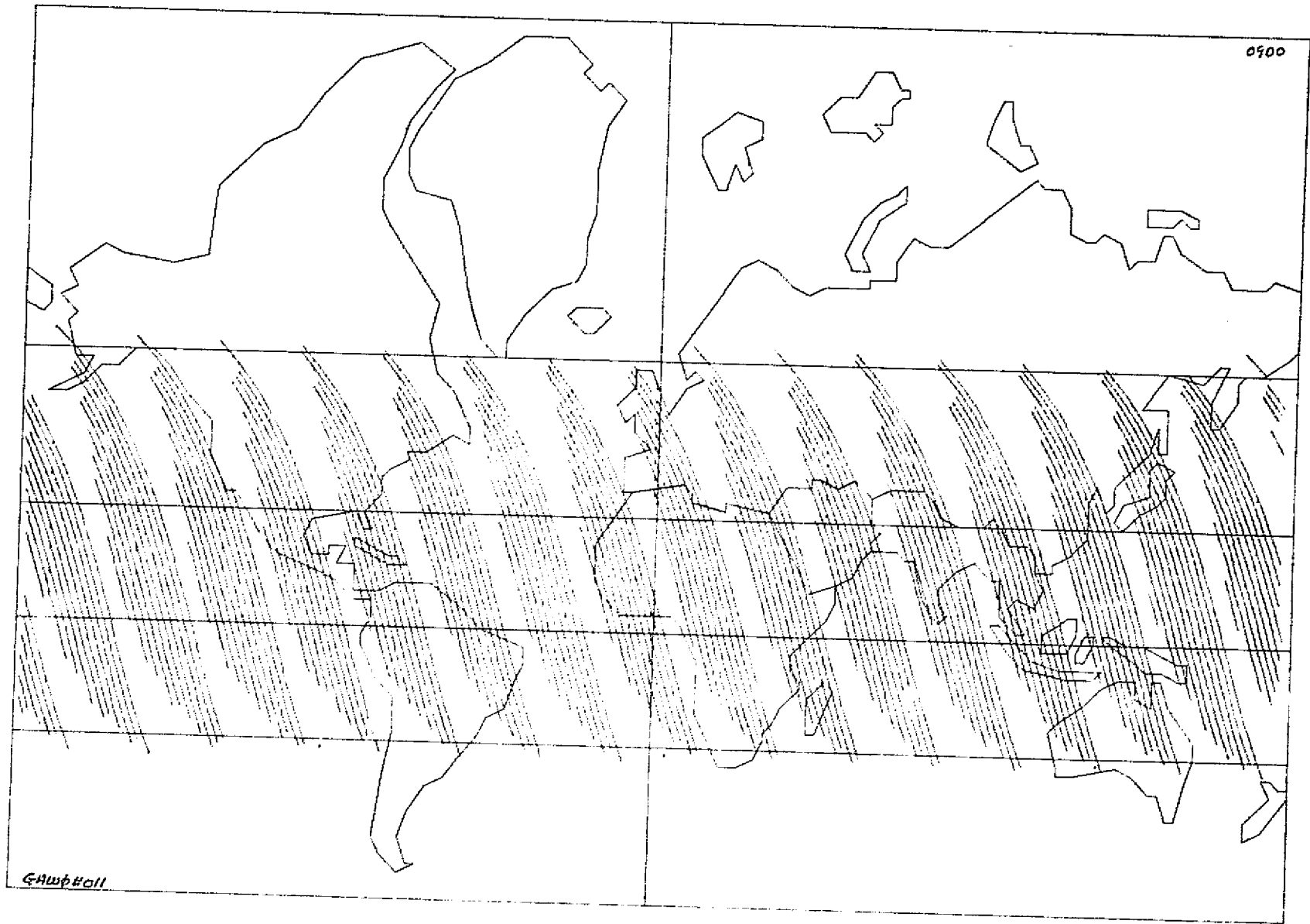


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FIGURE PACK 9 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

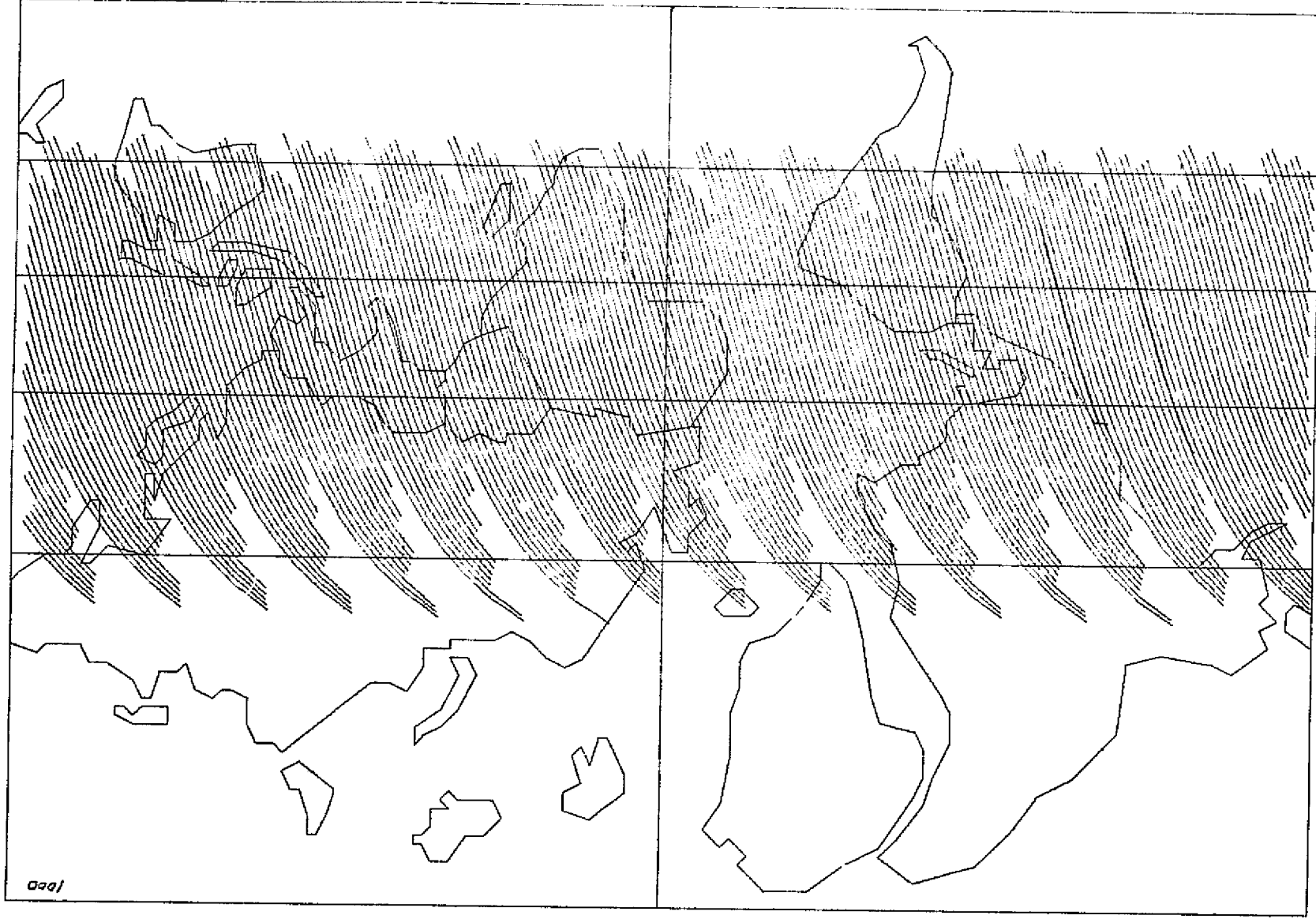
Data:

Launch site	VAFB
Inclination	70 degrees
Altitude	269.6 kilometers
Launch date	1 July
Launch time	0900 to 1500 hours (hourly)

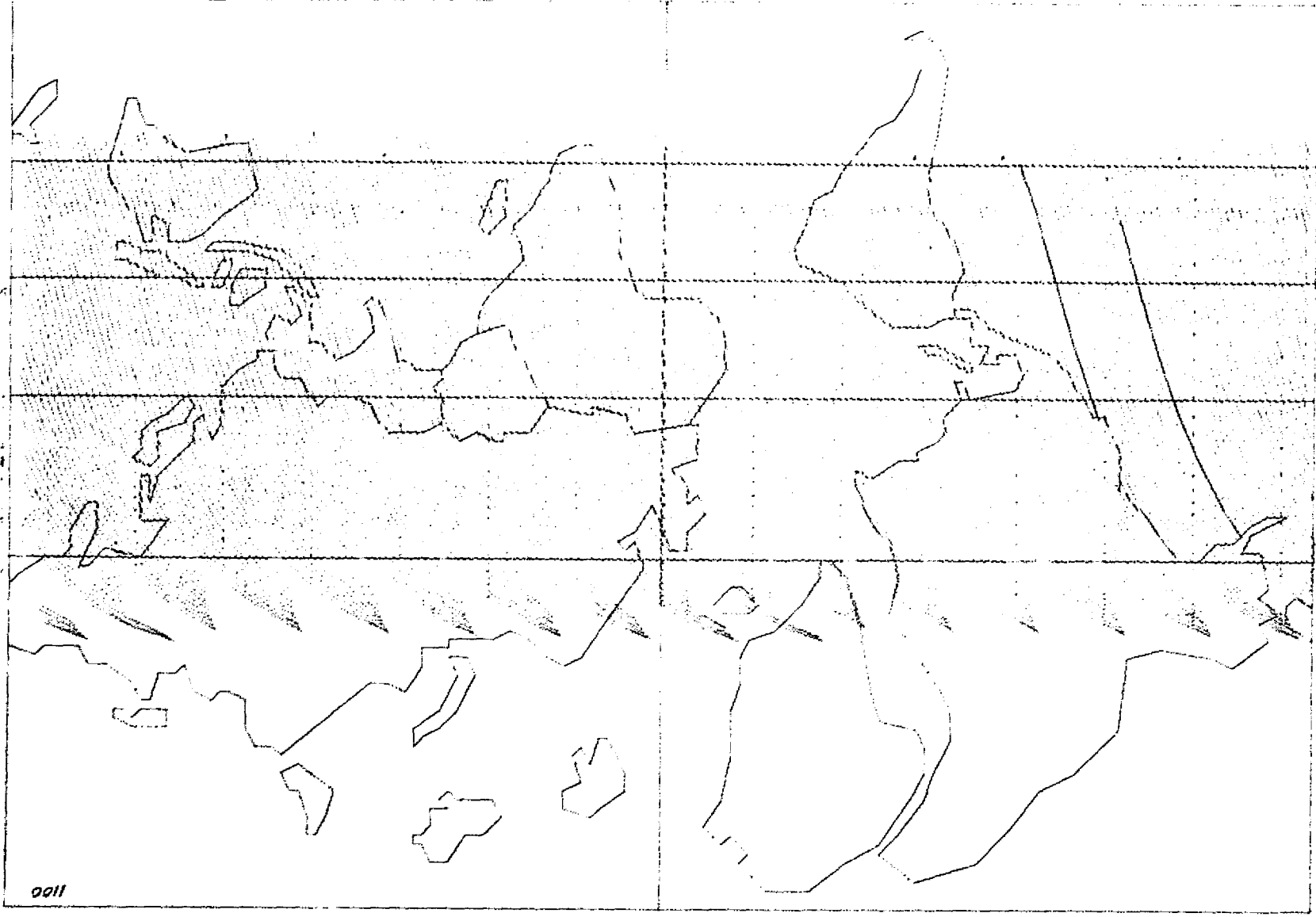


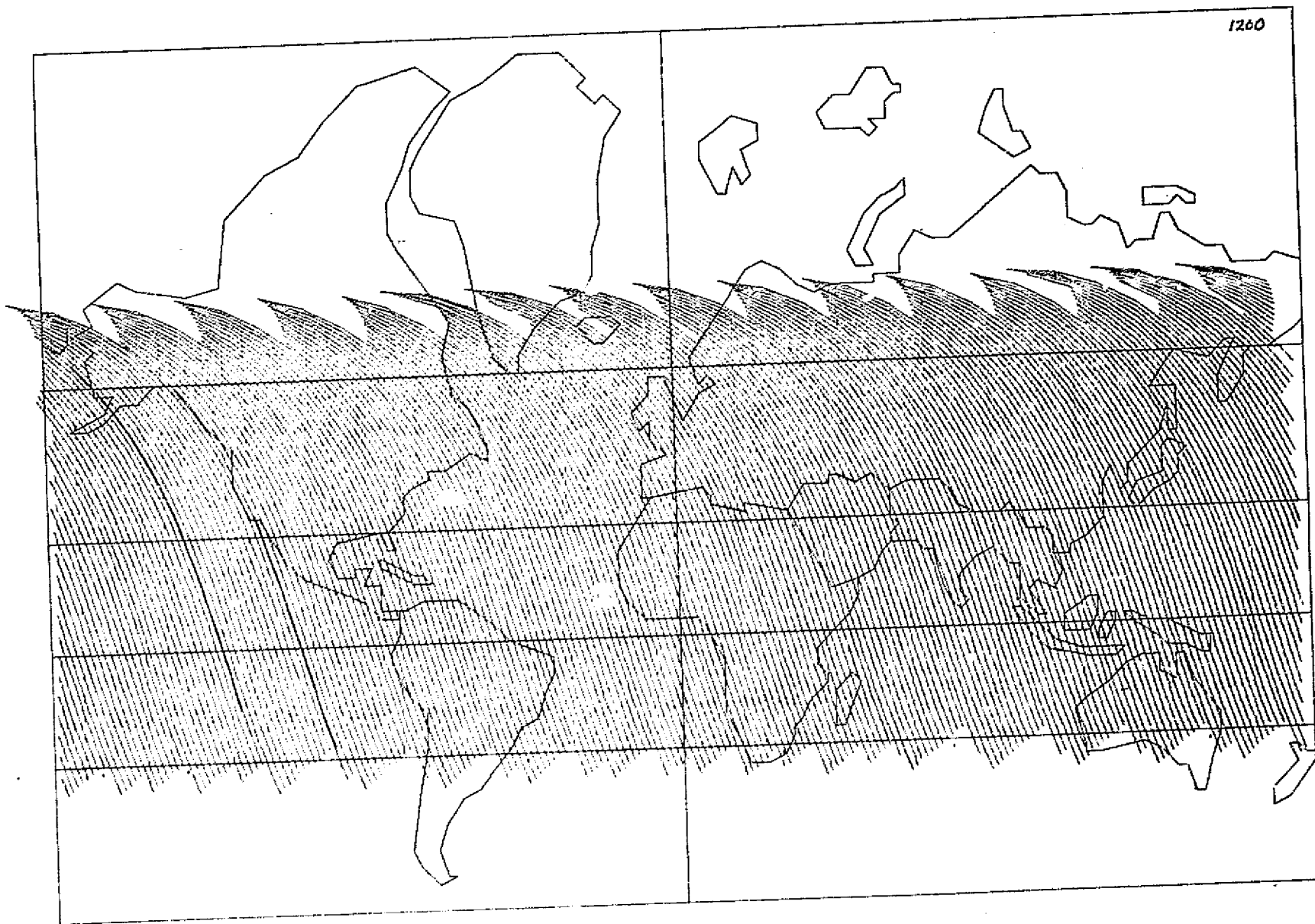
B-68

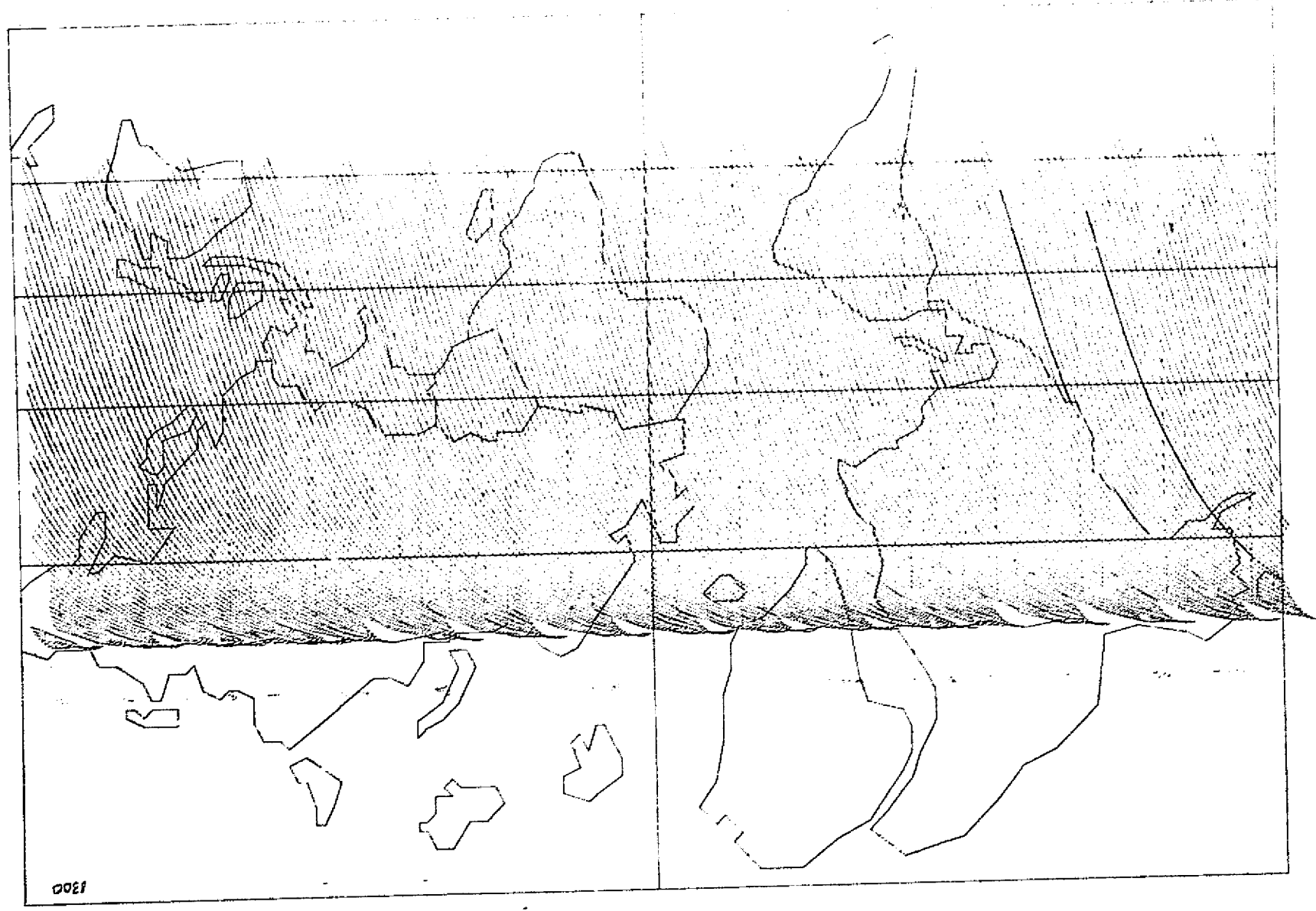
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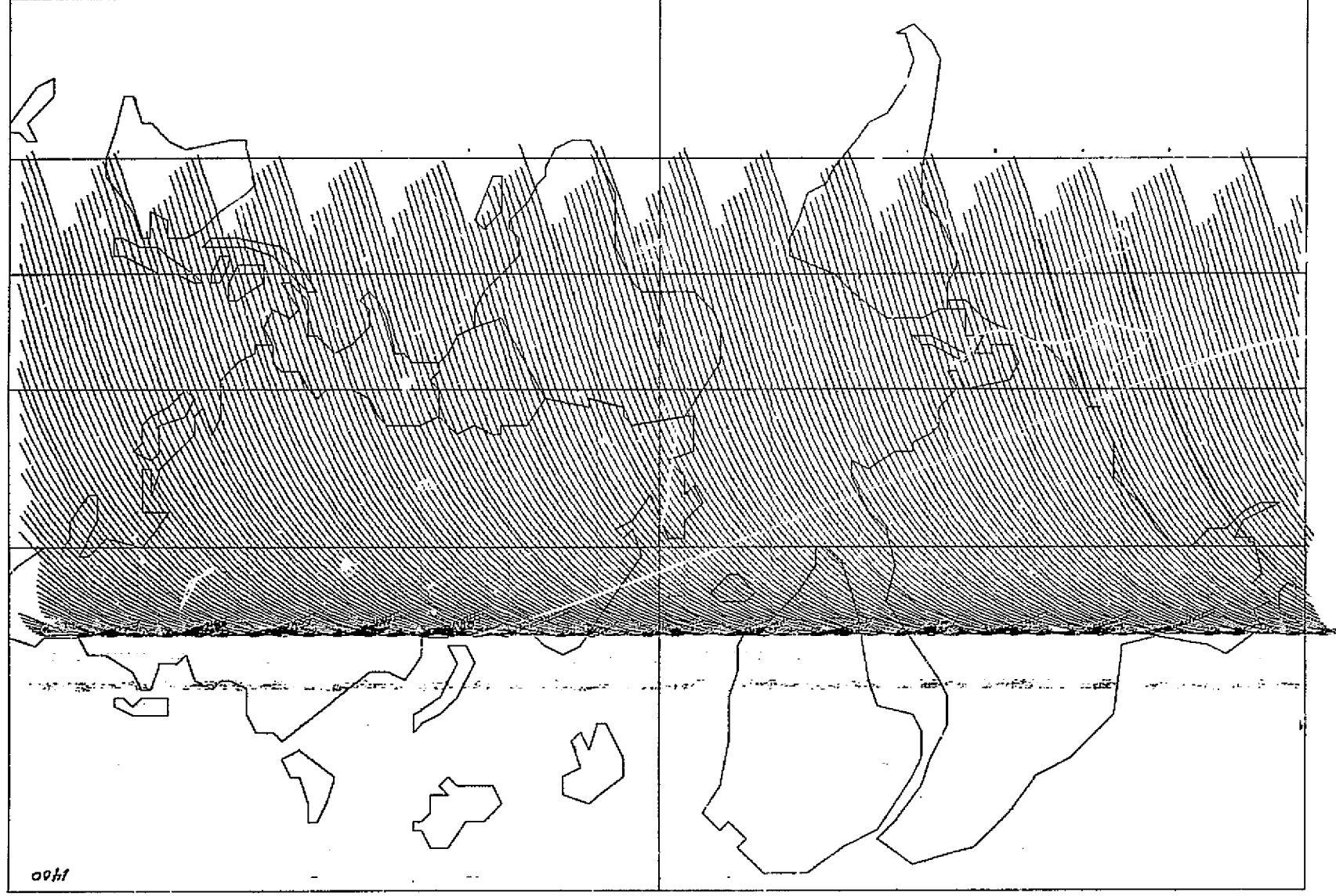
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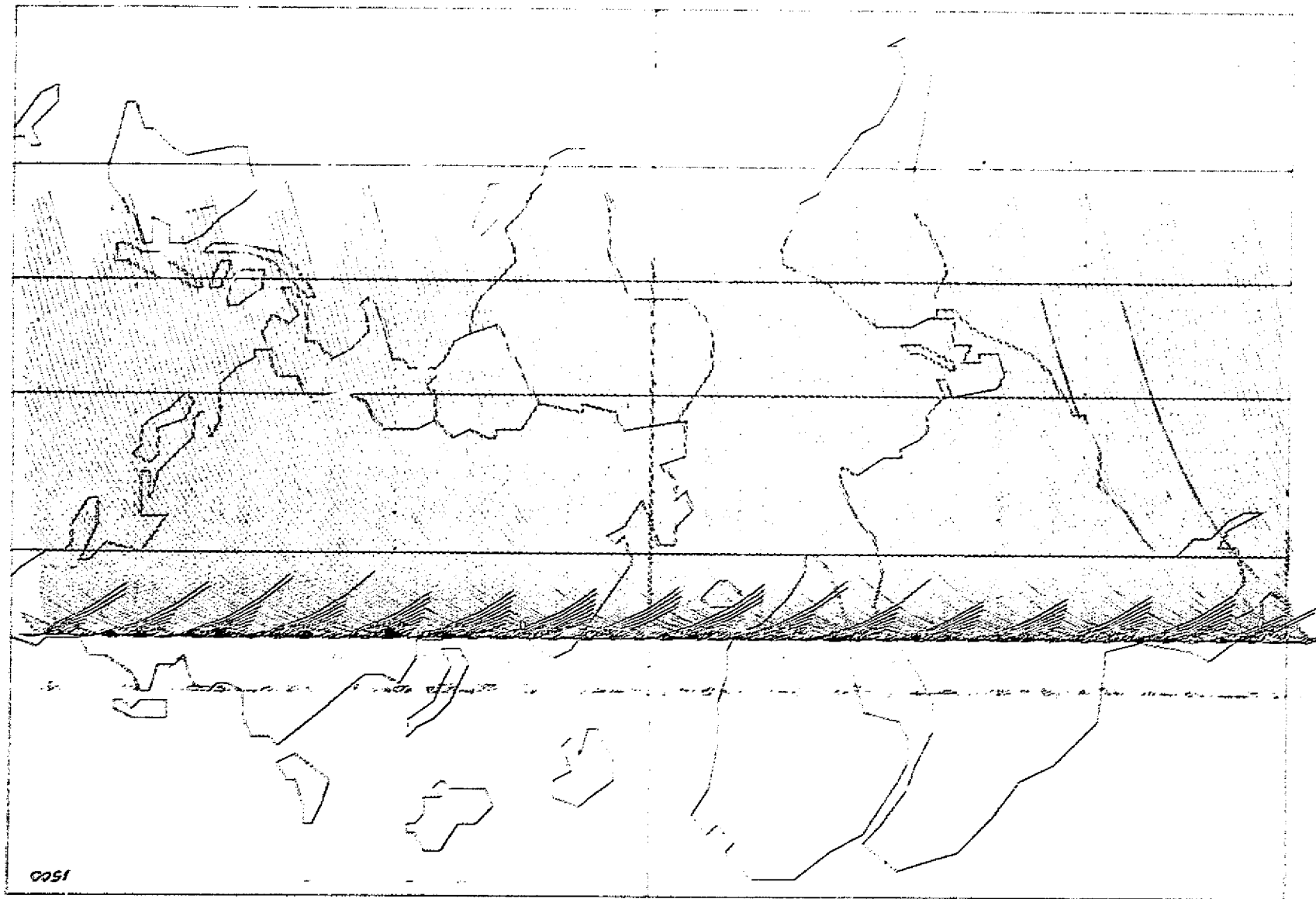
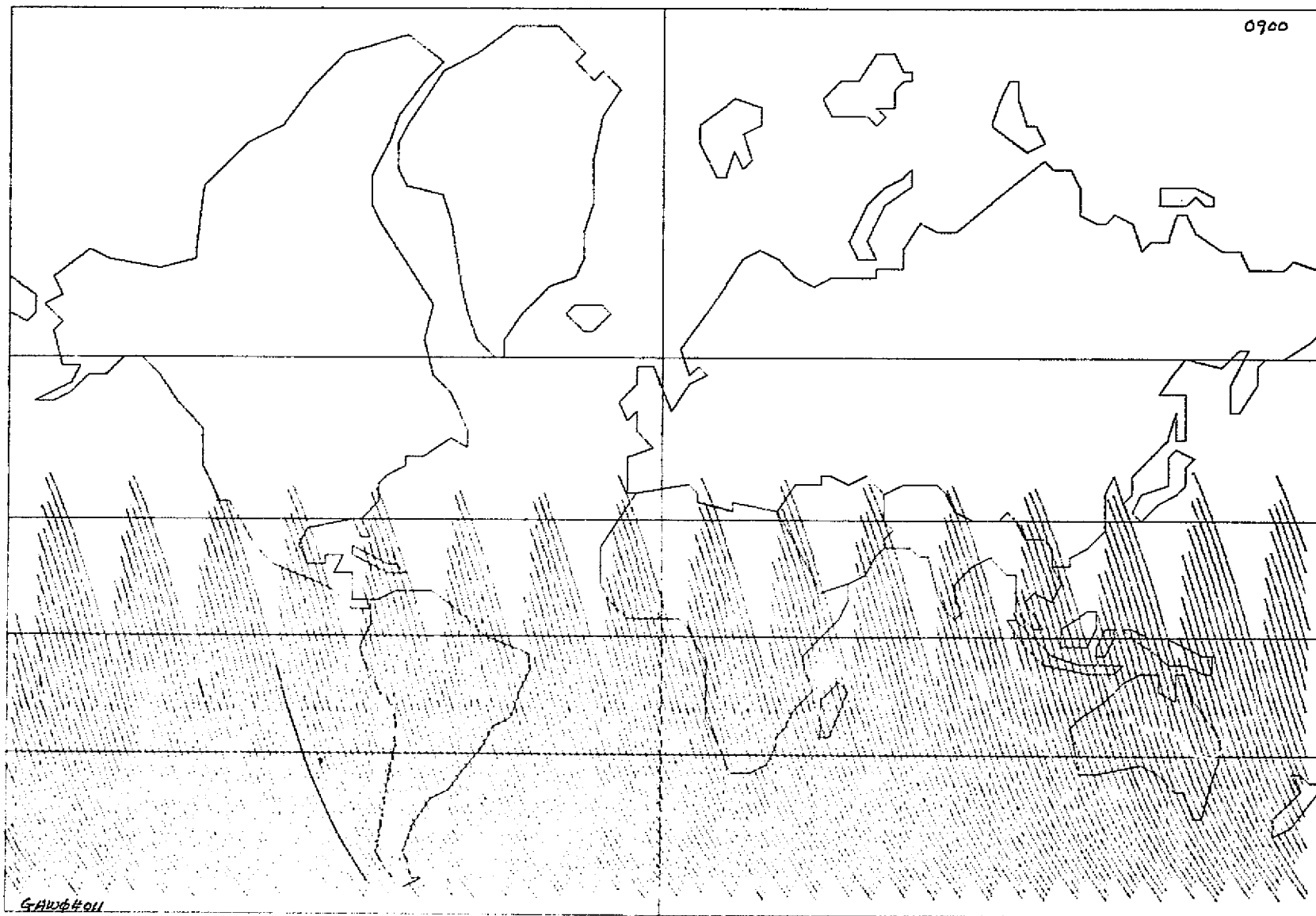


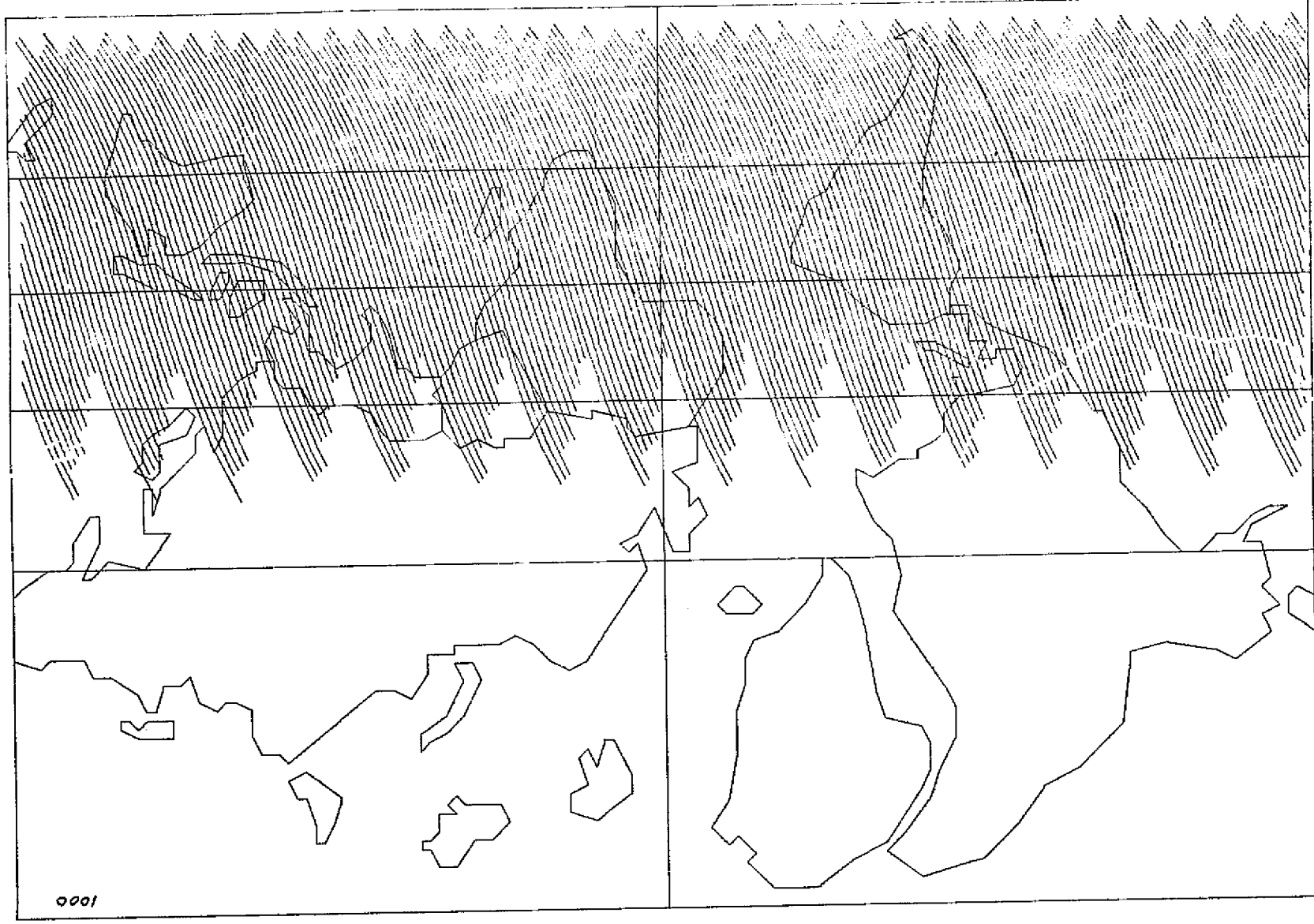
FIGURE PACK 10 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

Data:

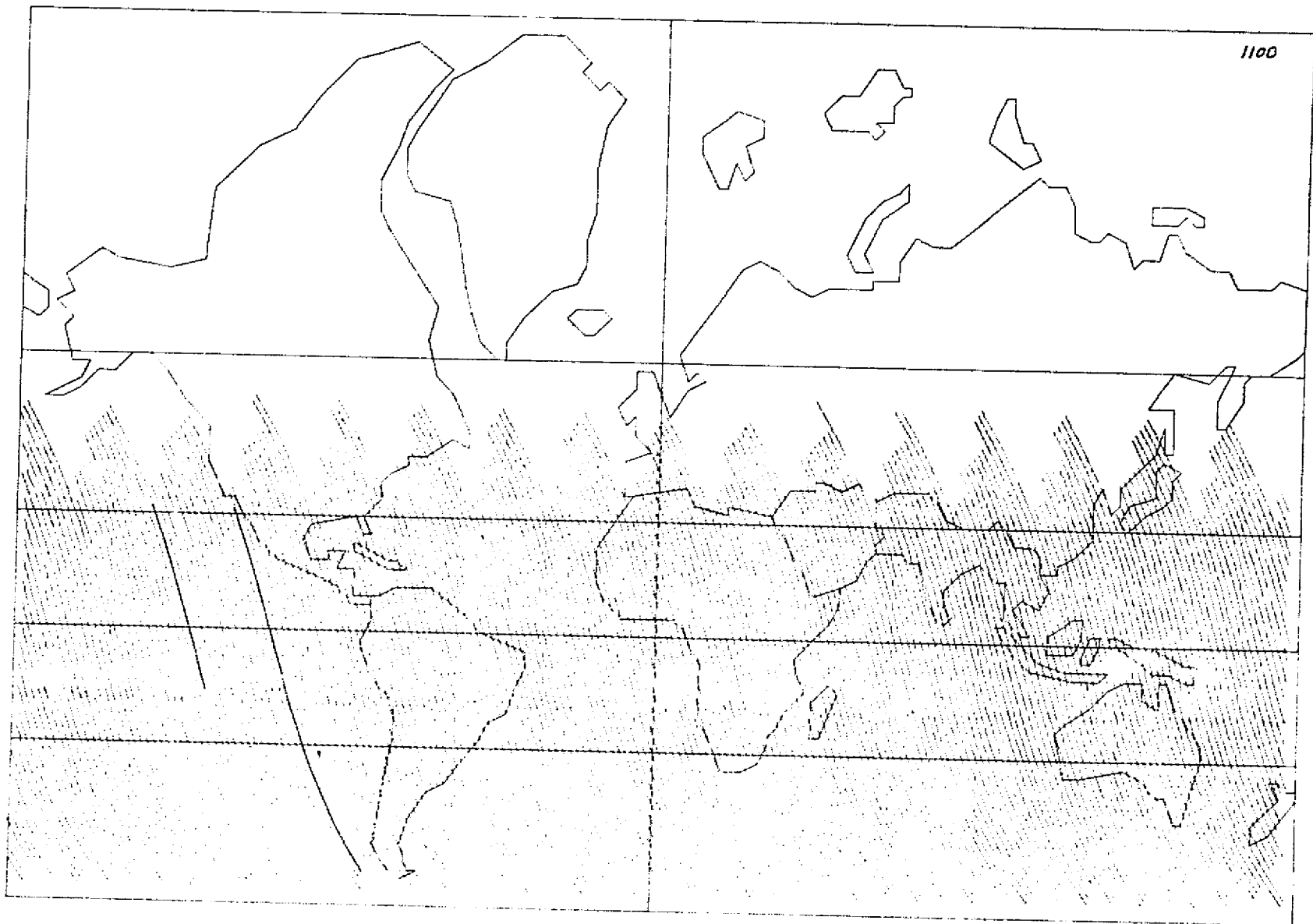
Launch site	VAFB
Inclination	70 degrees
Altitude	269.6 kilometers
Launch date	1 October
Launch time	0900 to 1500 hours (hourly)



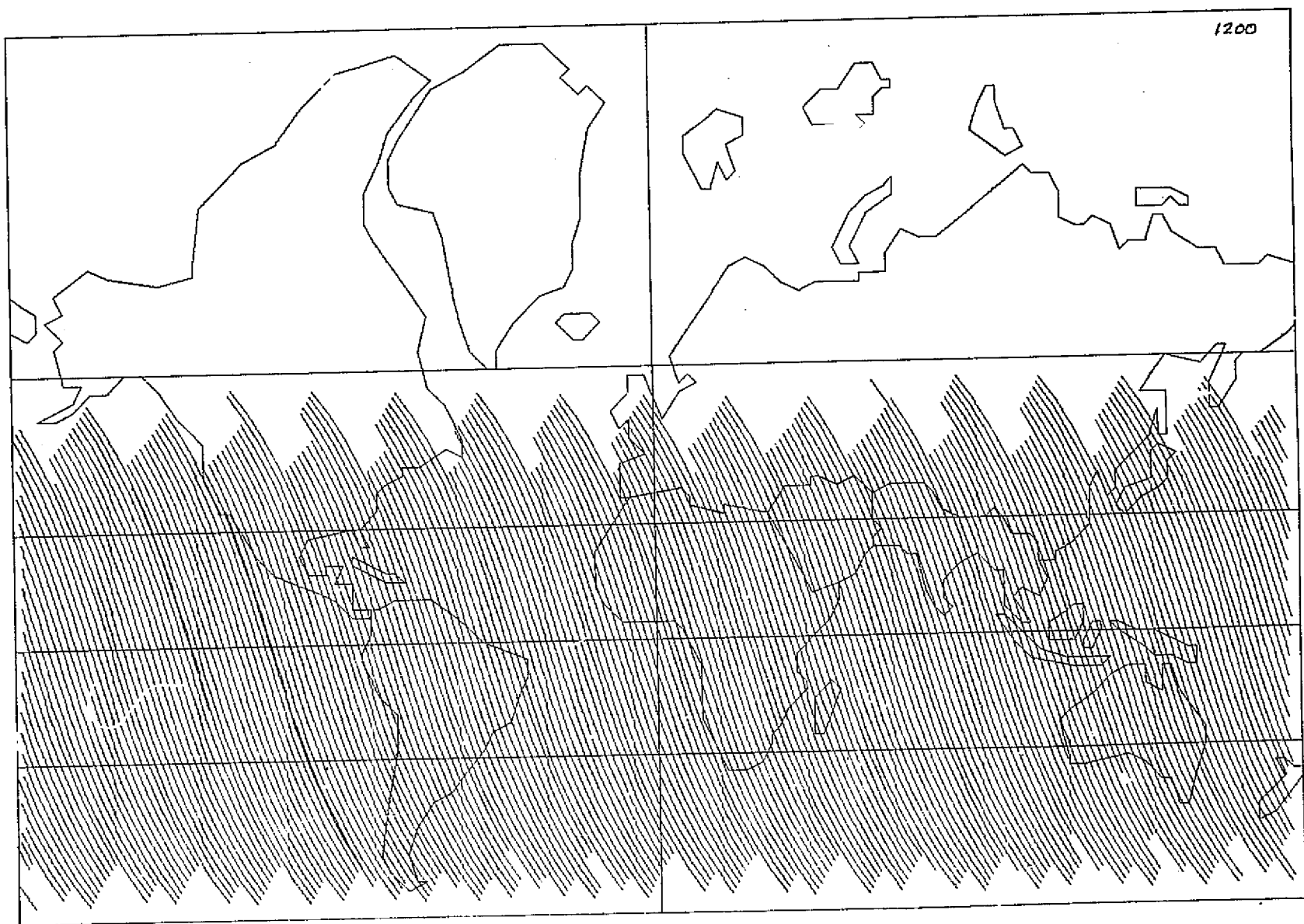
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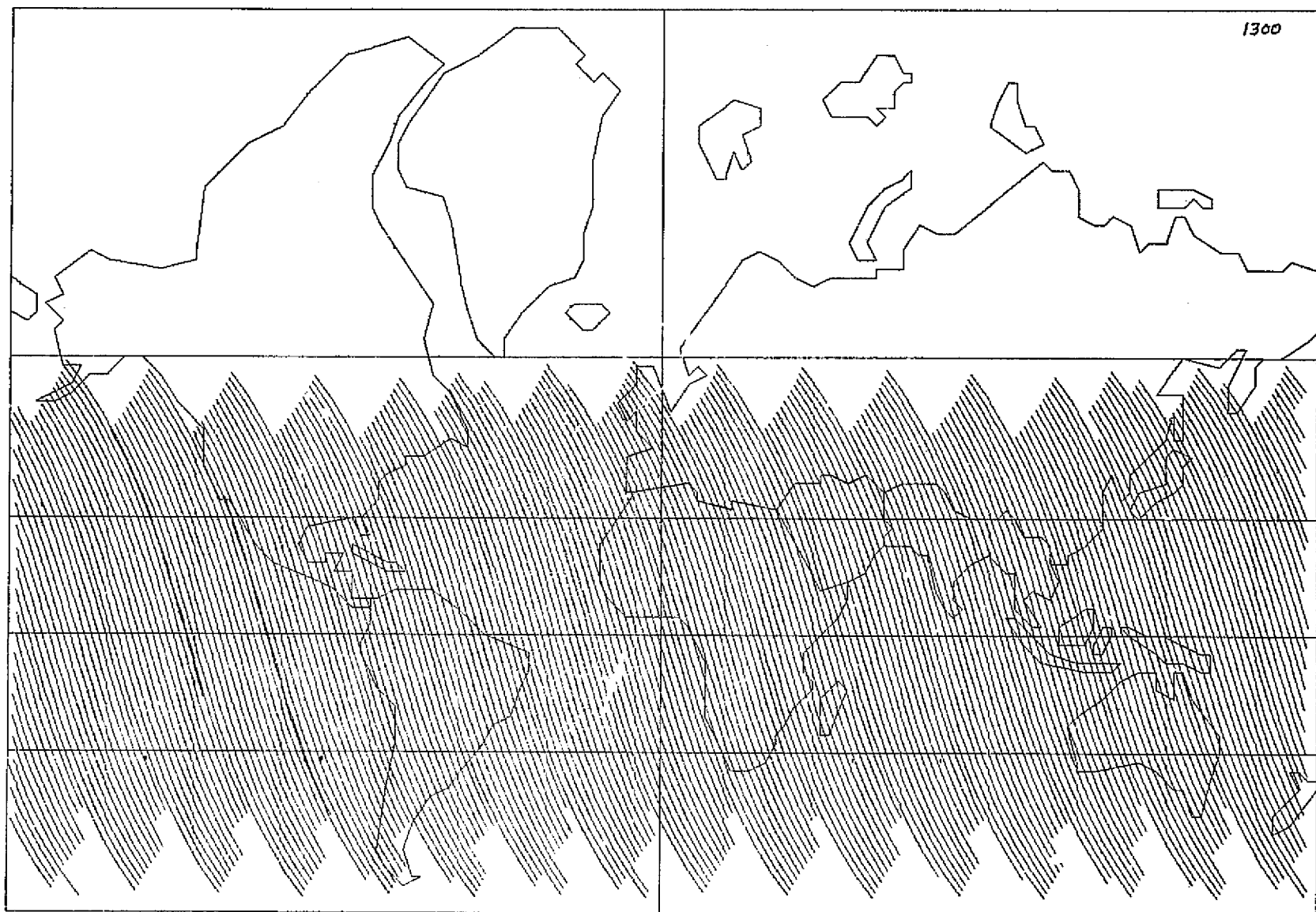


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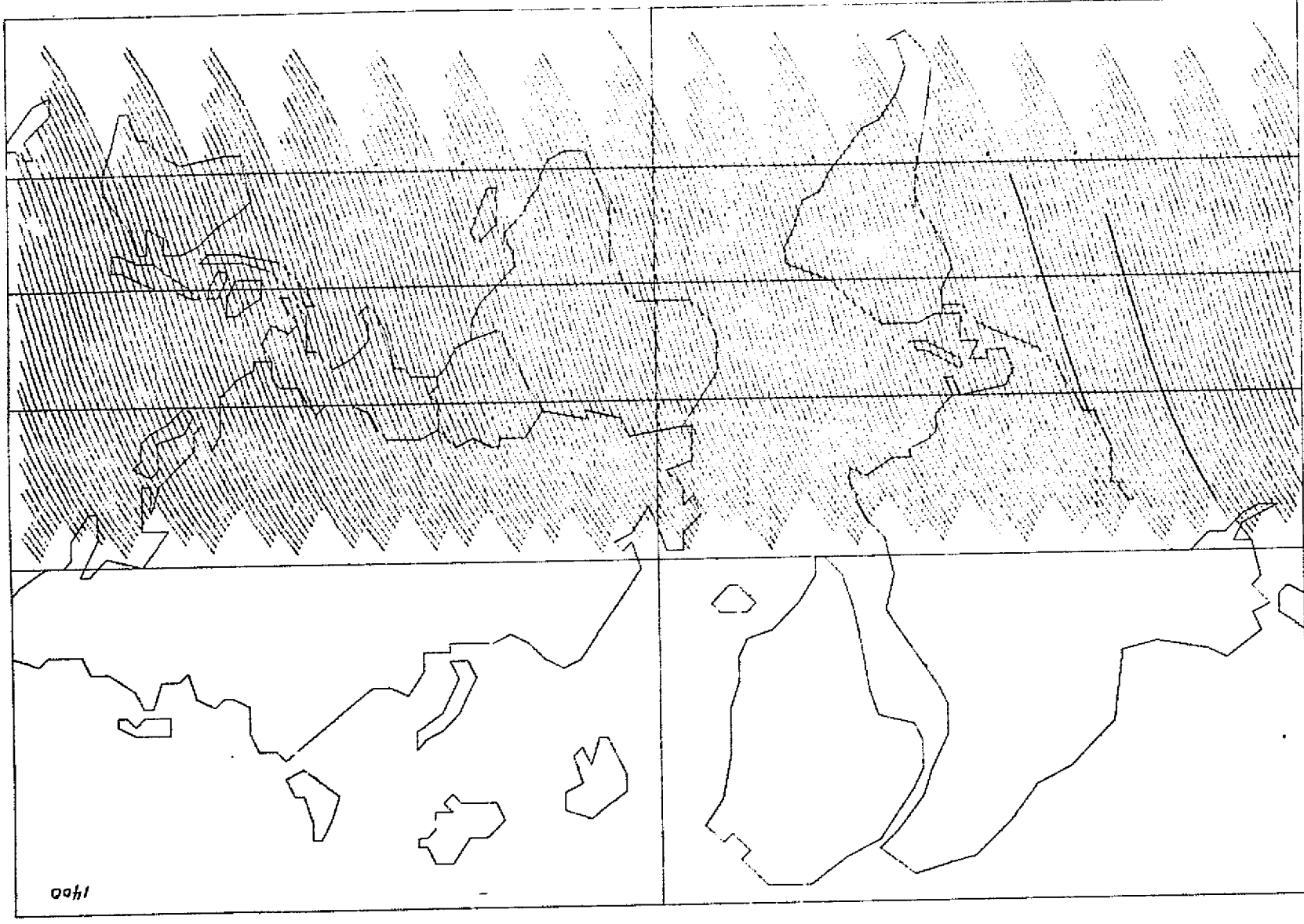
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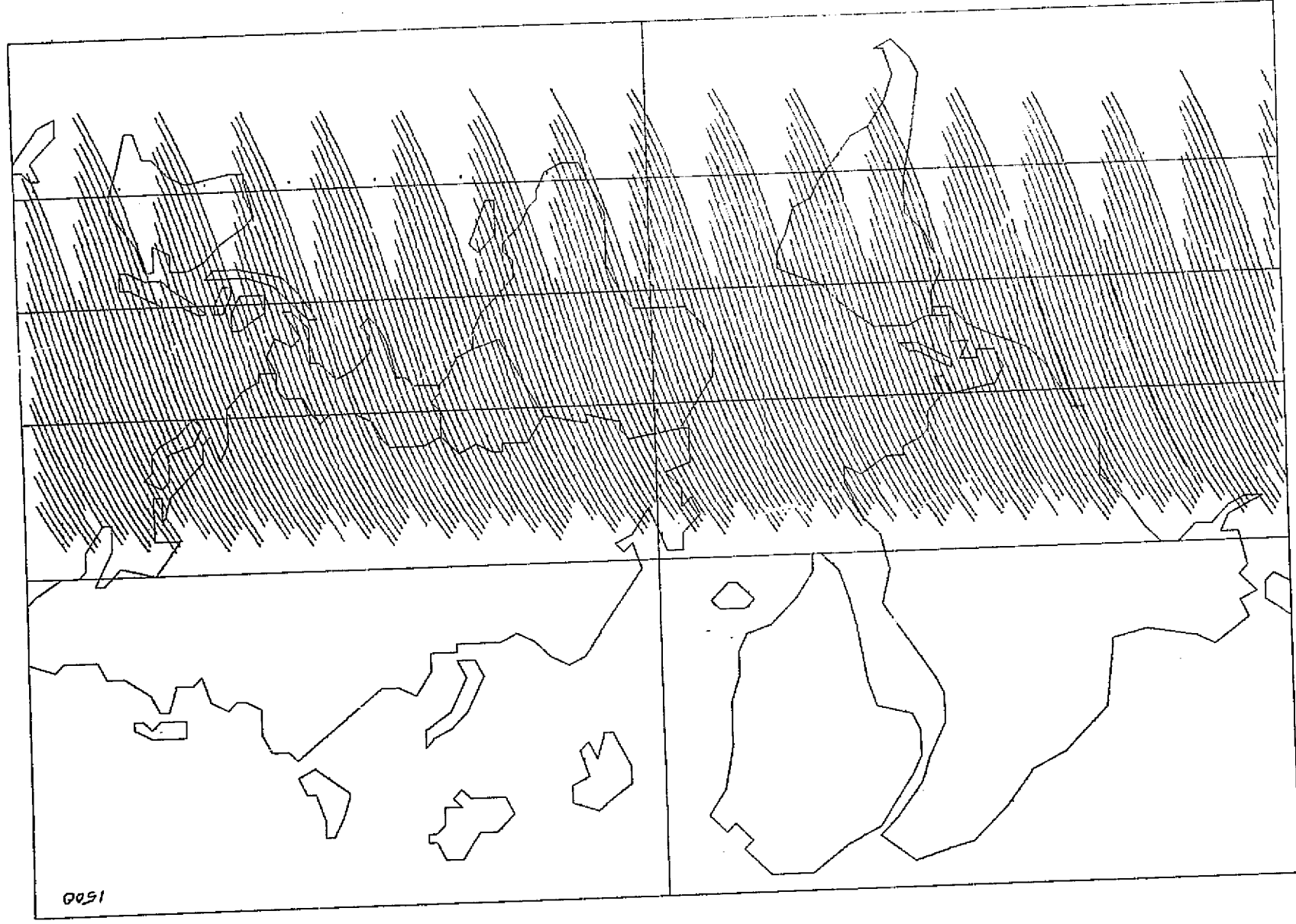
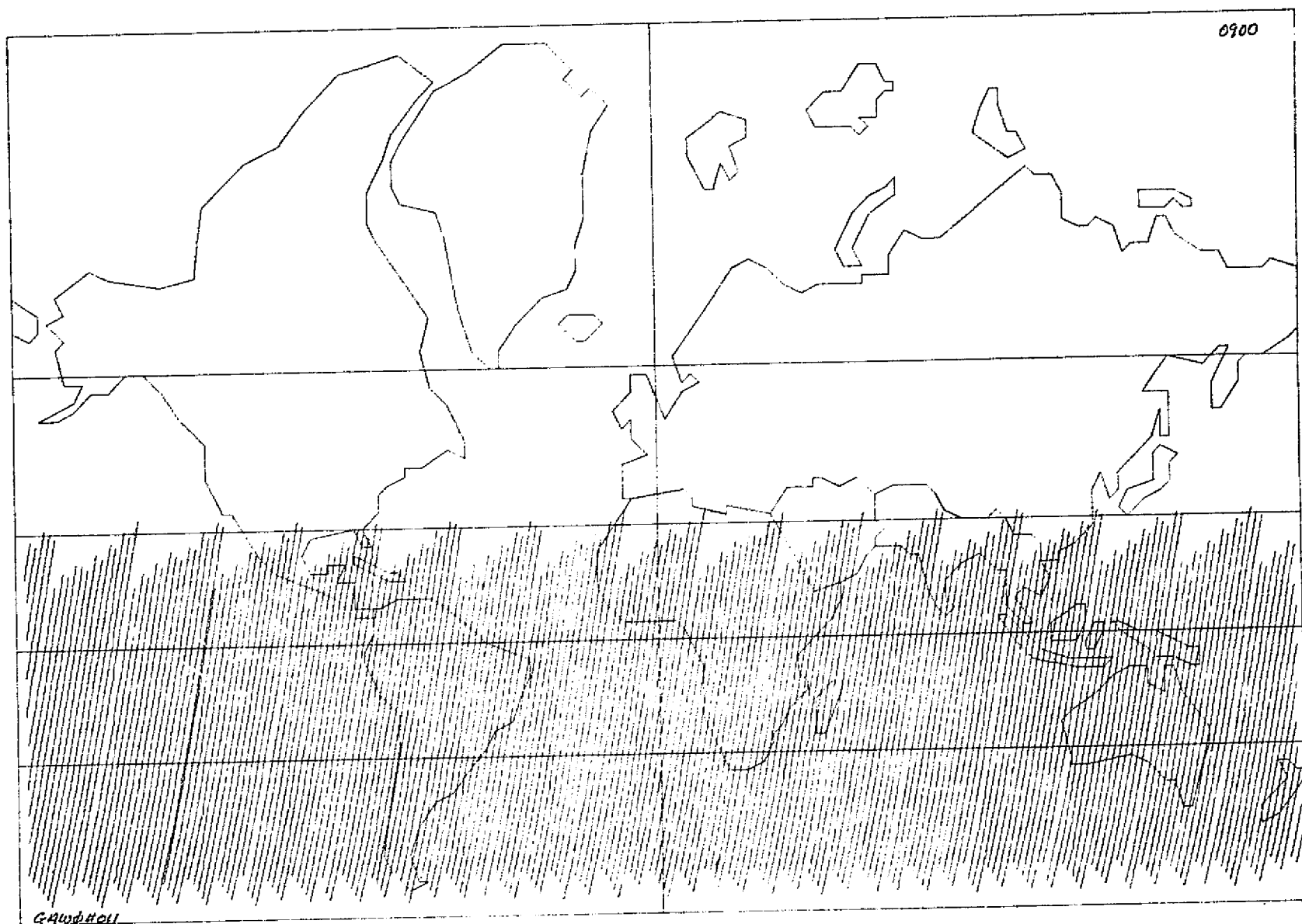


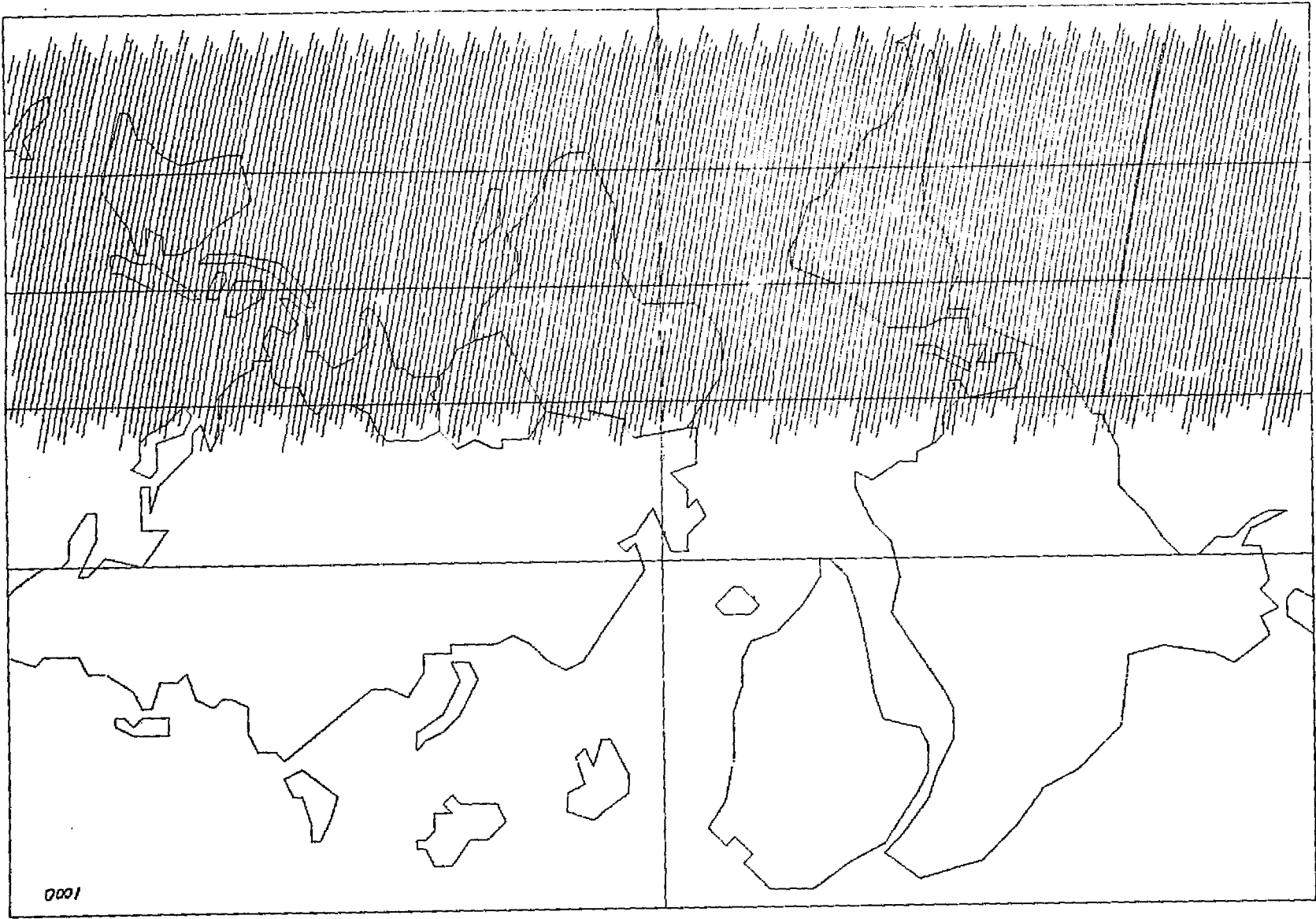
FIGURE PACK 11 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

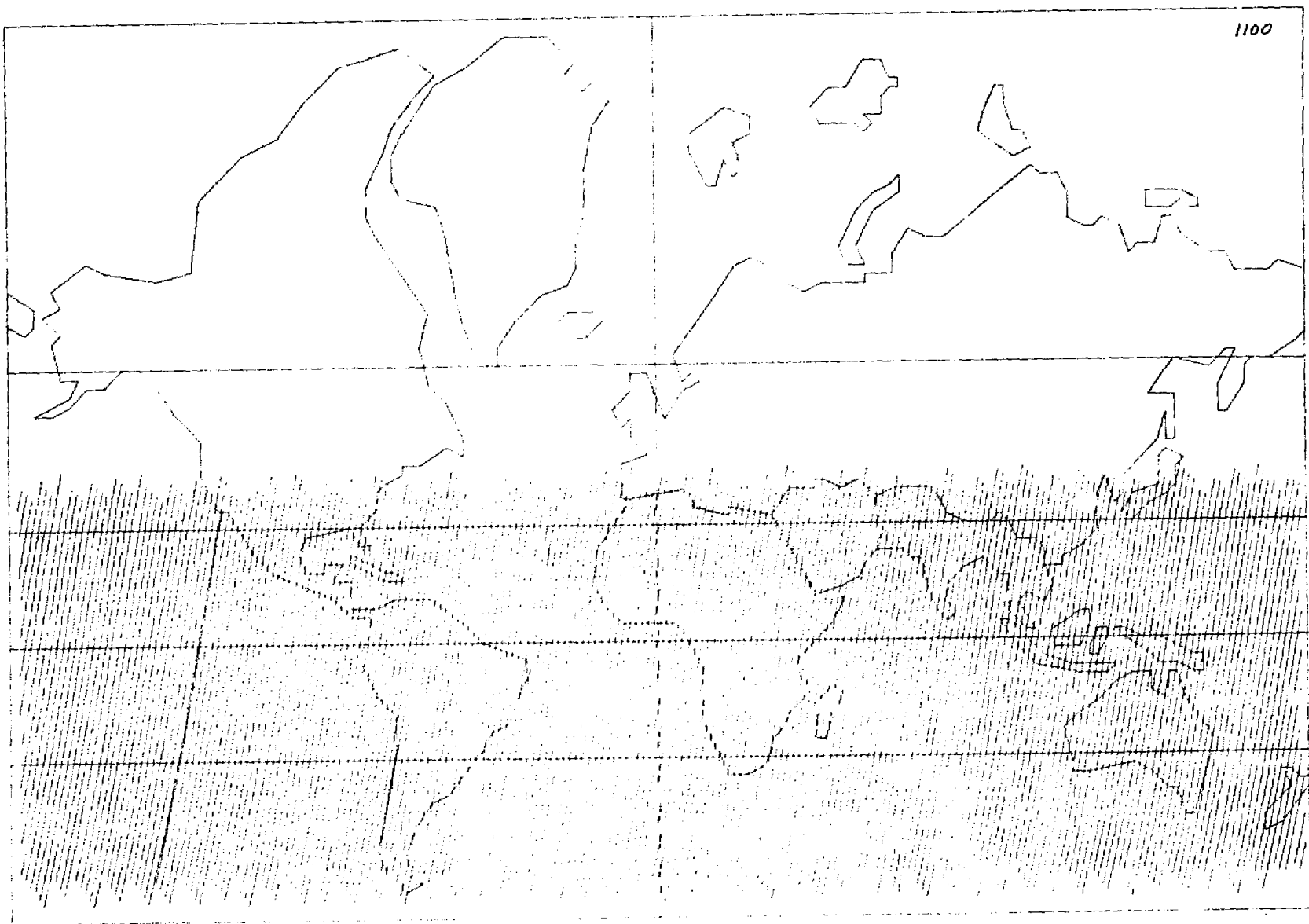
Data:

Launch site	VAFB
Inclination	96.6 degrees
Altitude	273.7 kilometers
Launch date	1 January
Launch time	0900 to 1500 hours (hourly)

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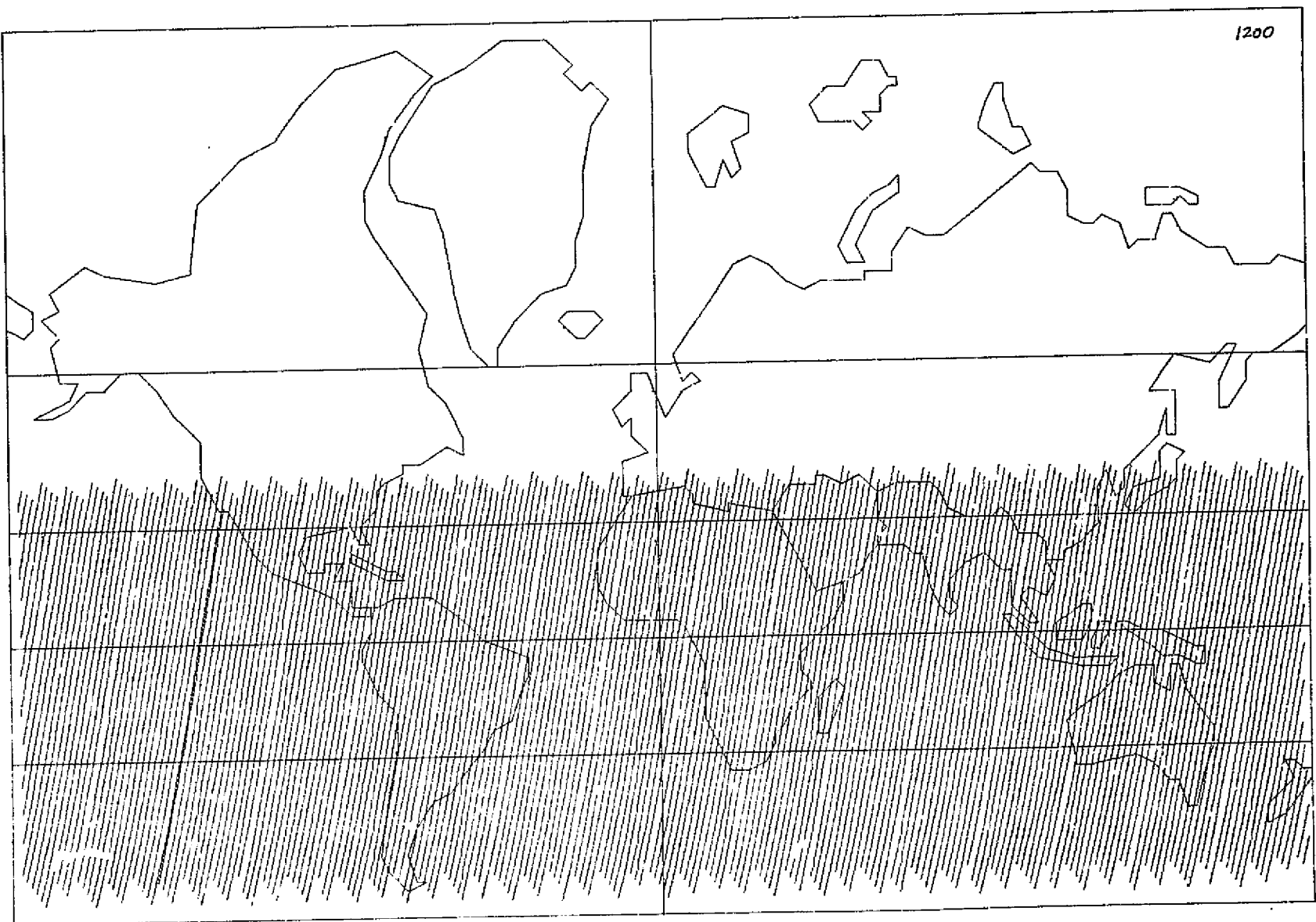


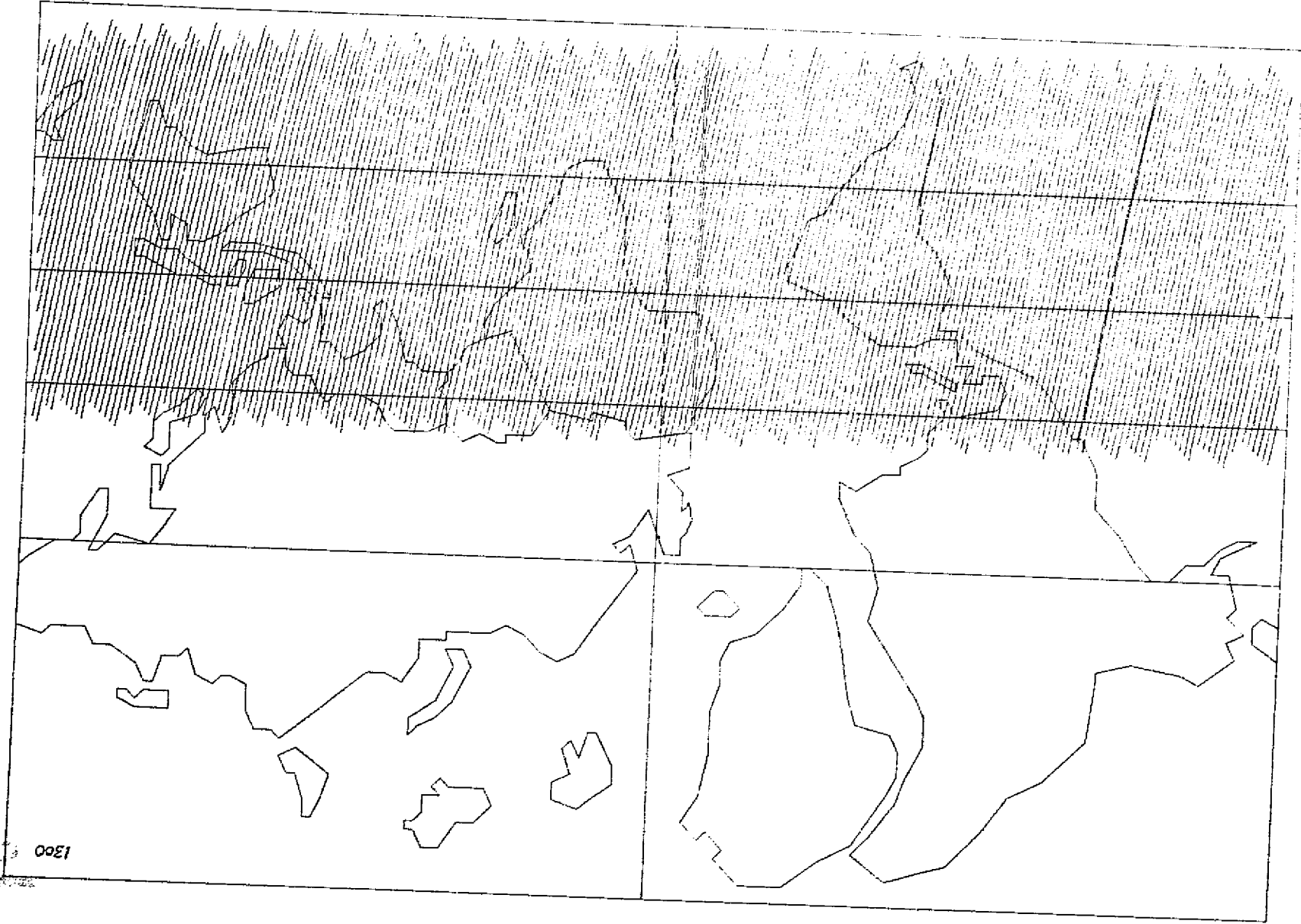


1100

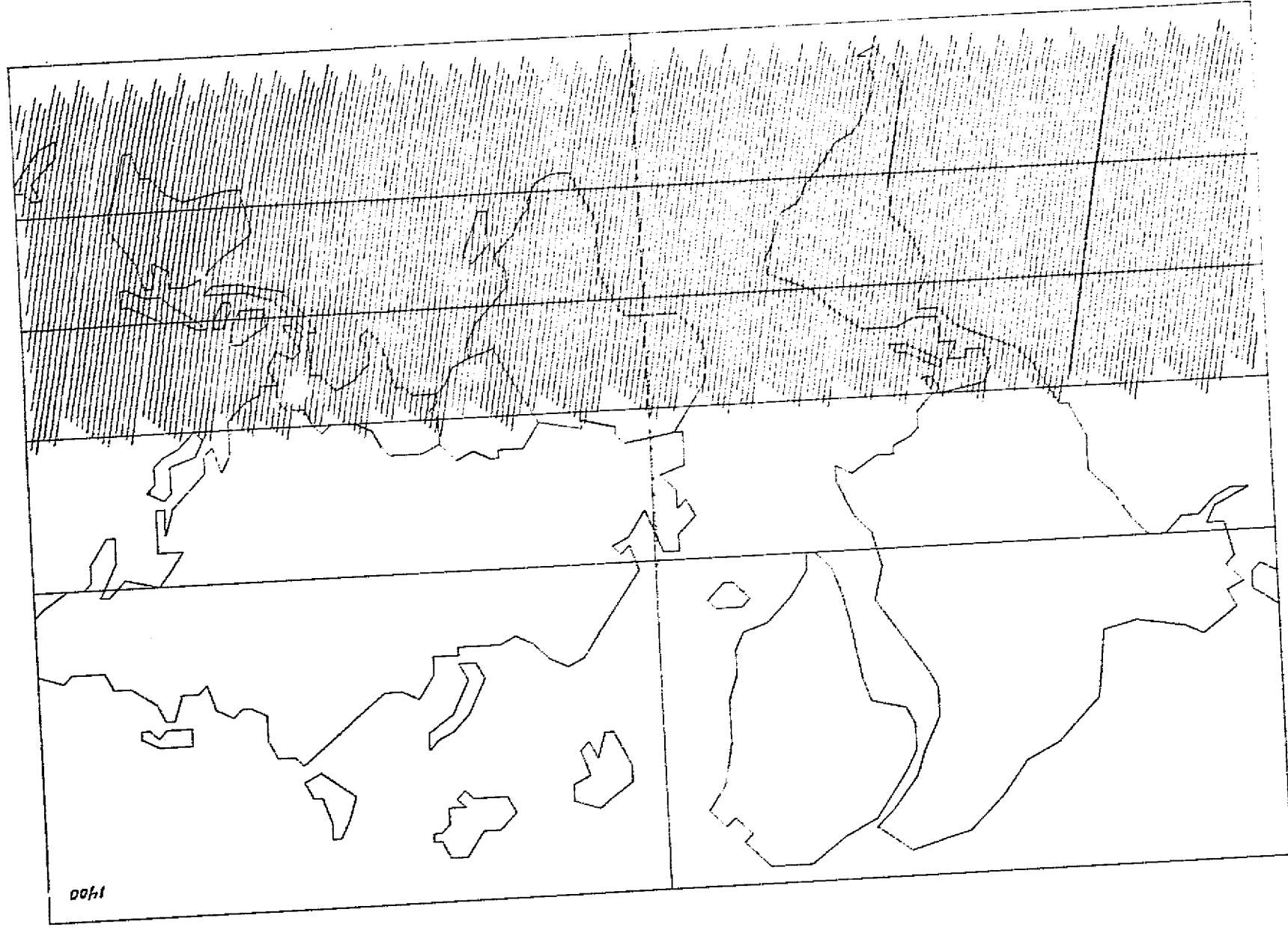
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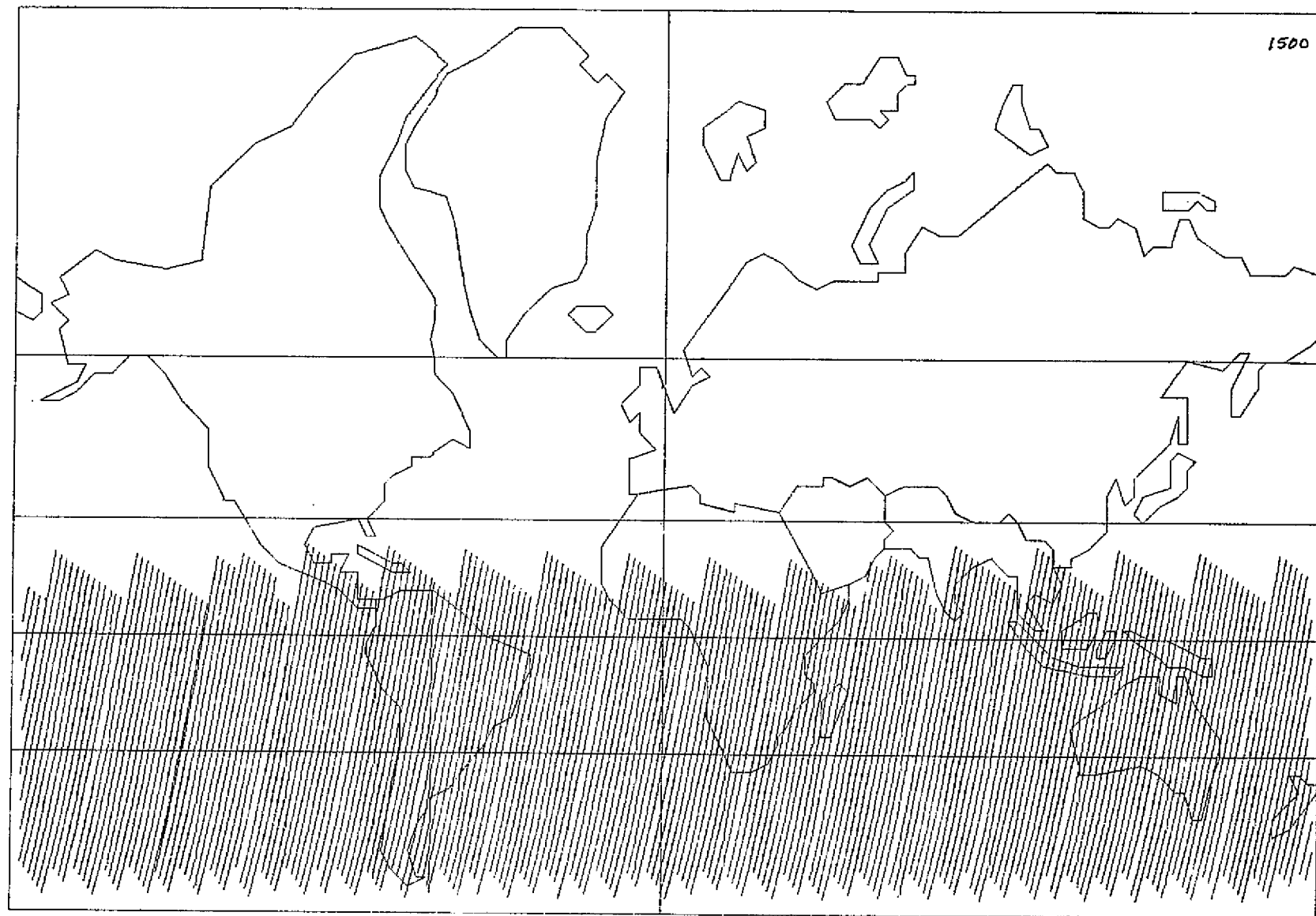
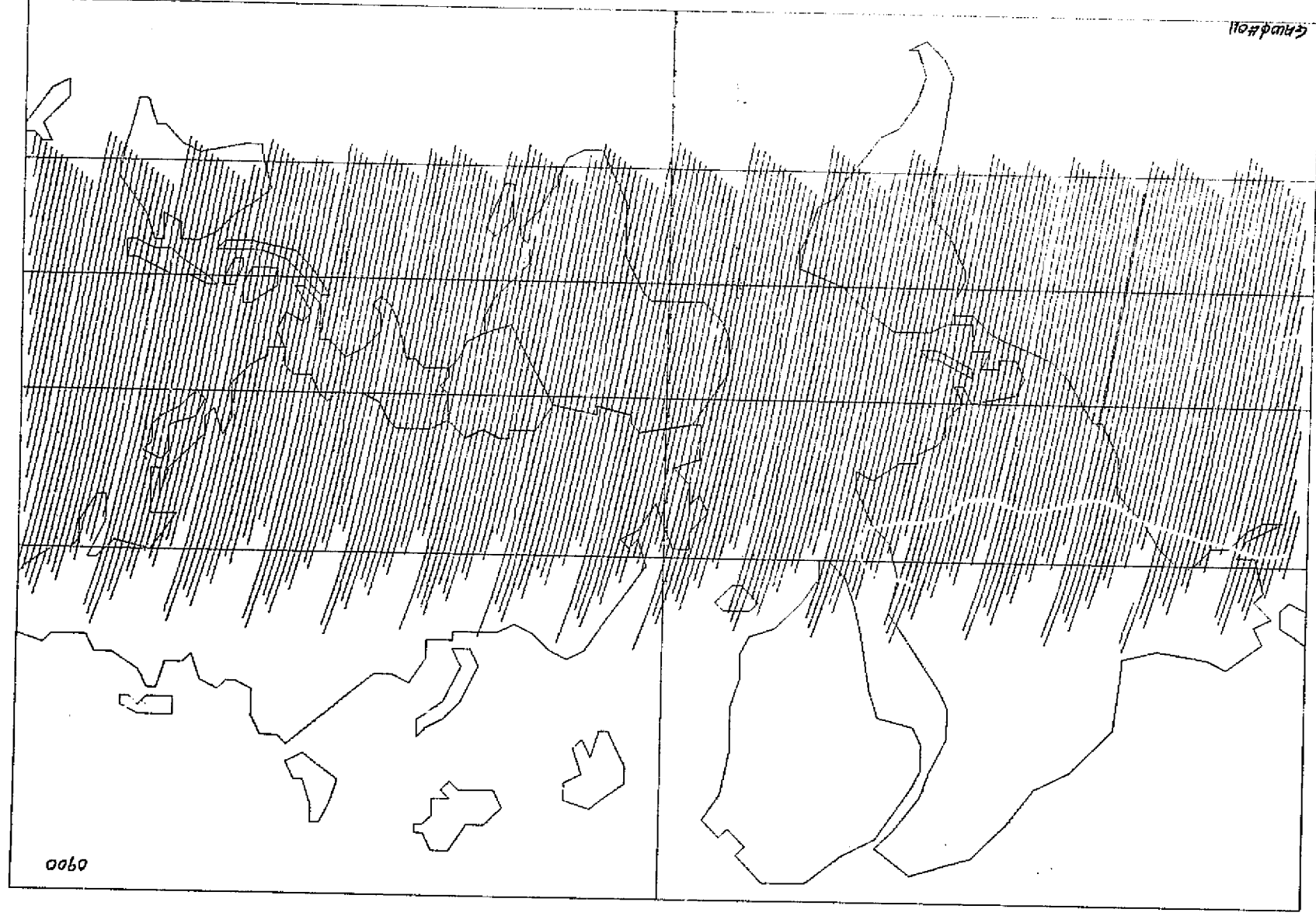


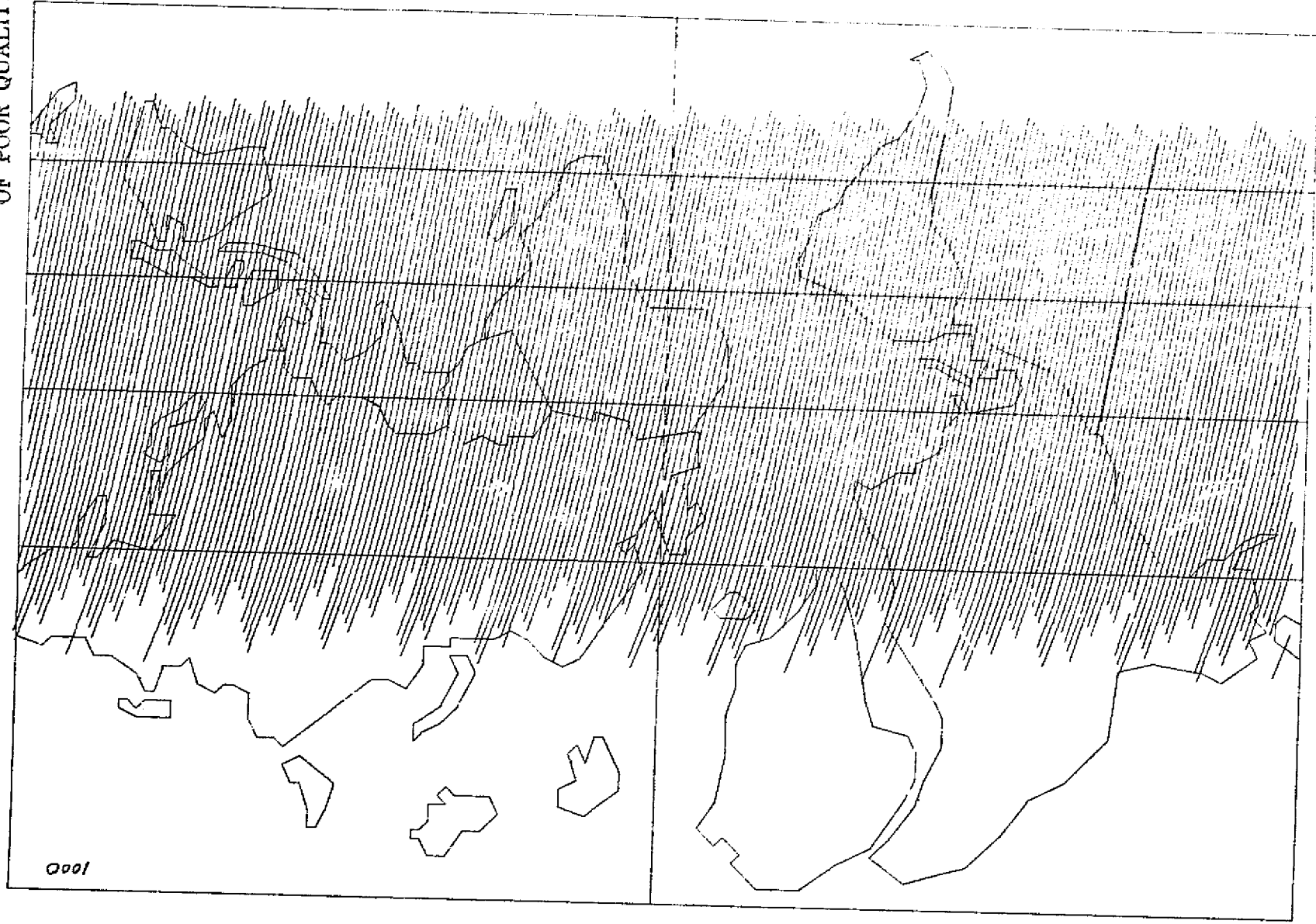
FIGURE PACK 12 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

Data:

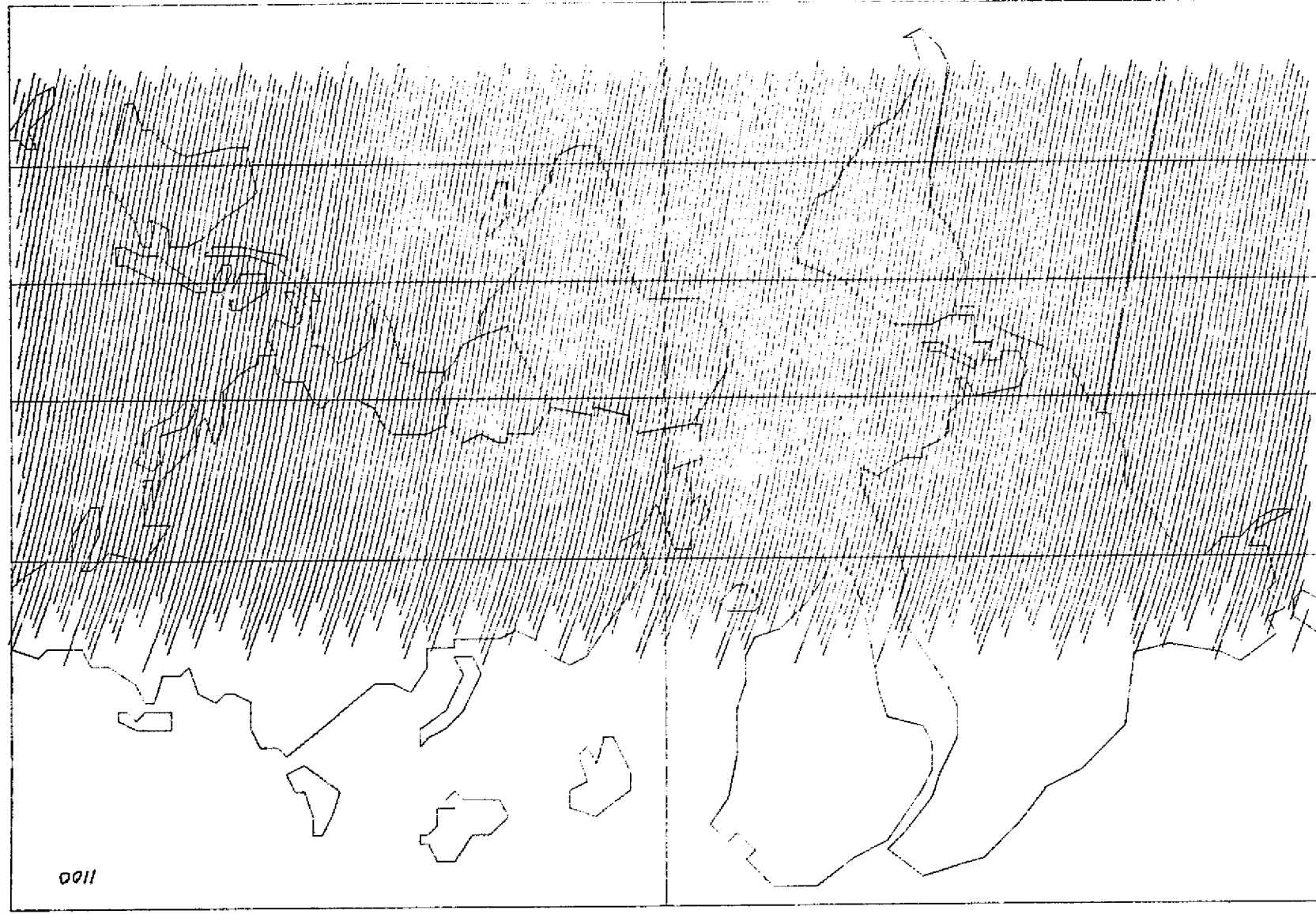
Launch site	VAFB
Inclination	96.6 degrees
Altitude	273.7 kilometers
Launch date	1 April
Launch time	0900 to 1500 hours (hourly)



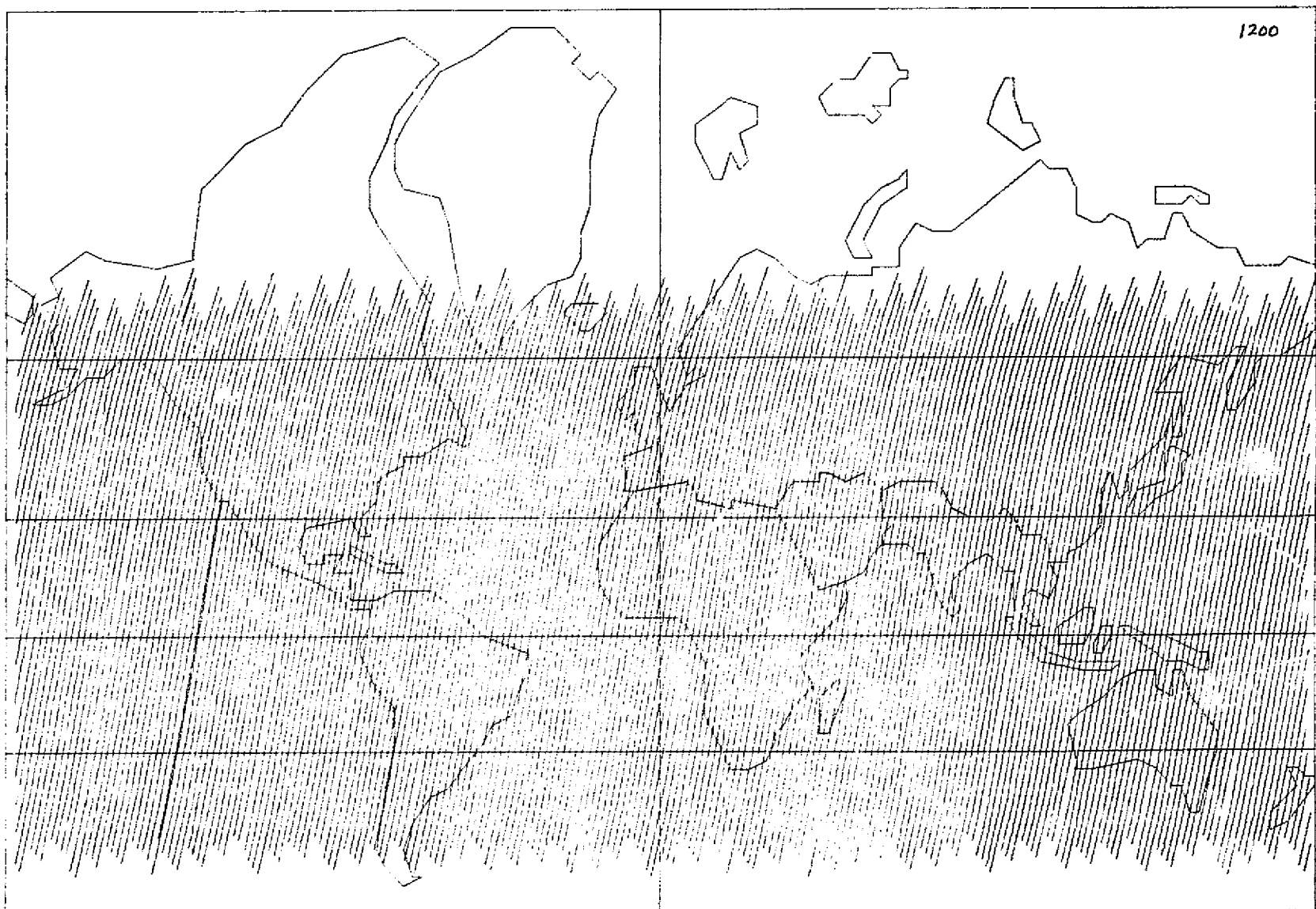
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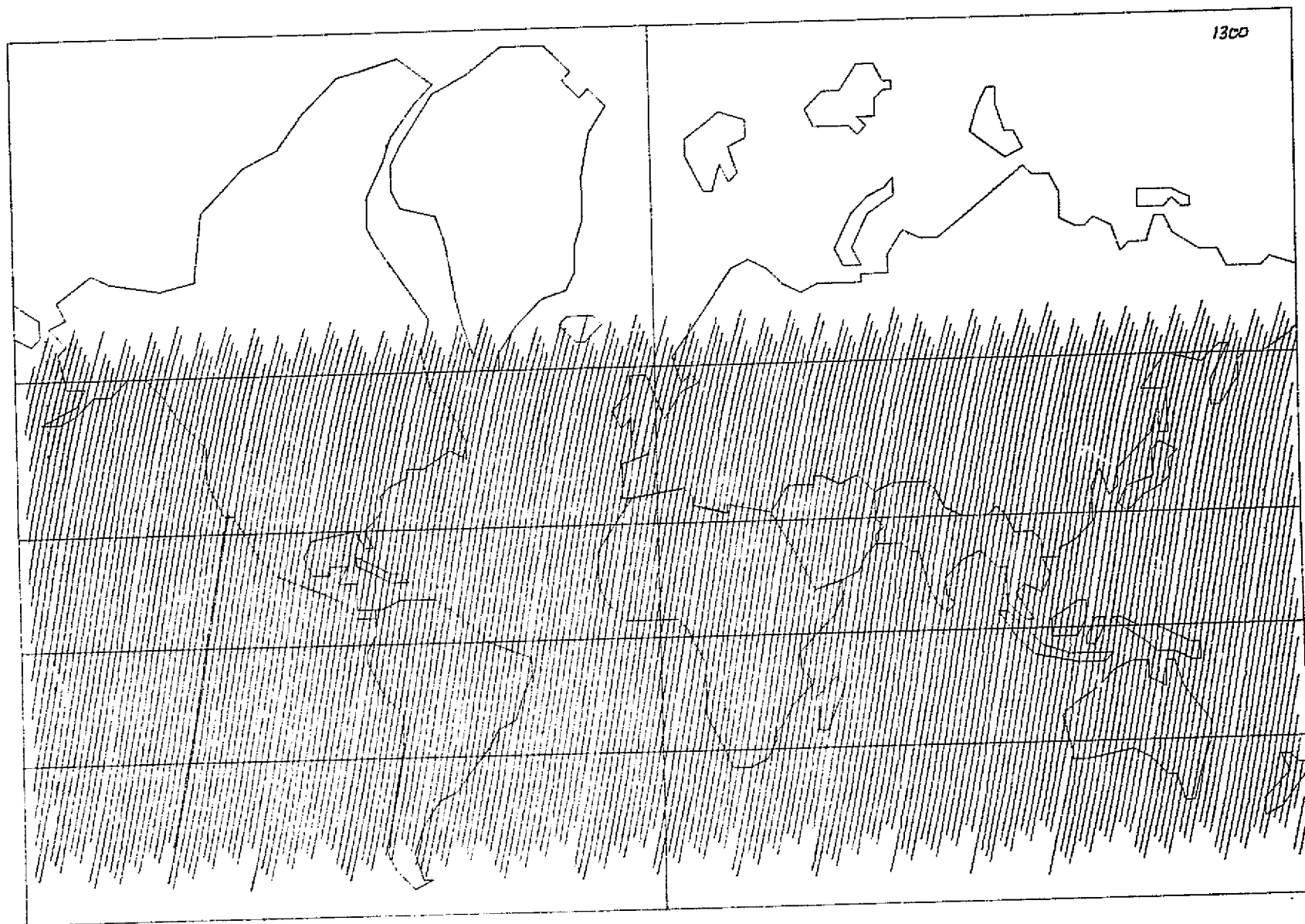


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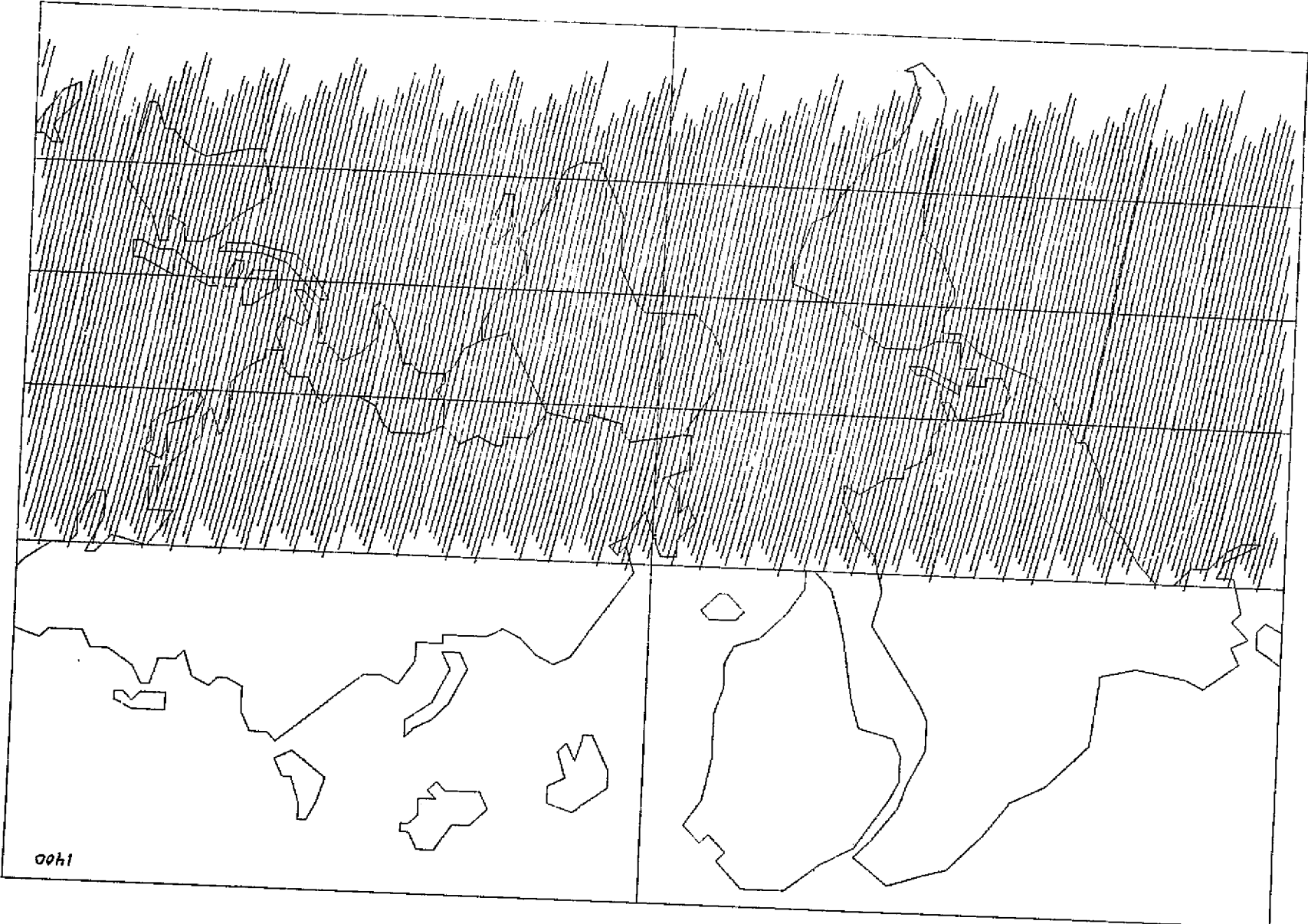


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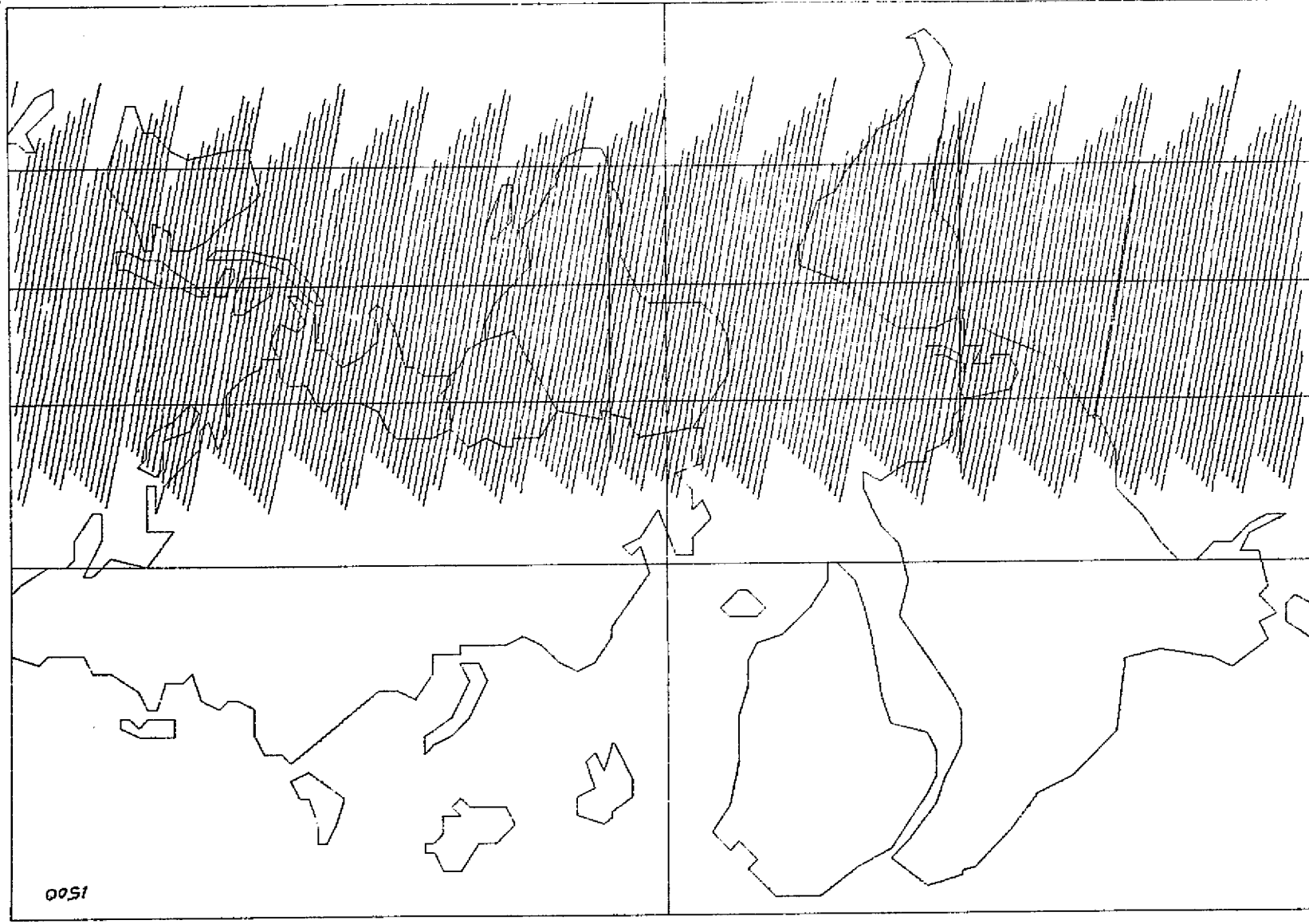
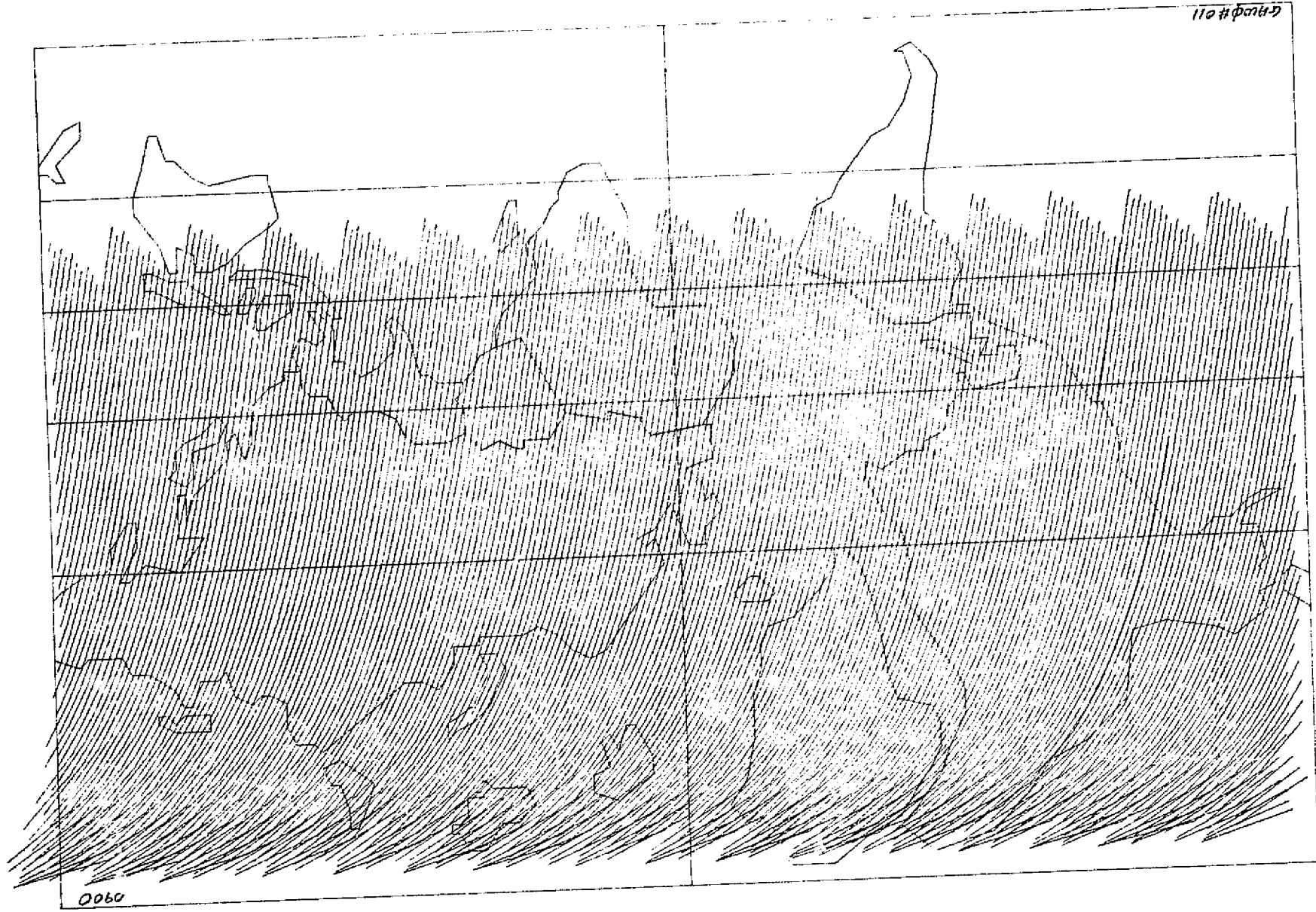


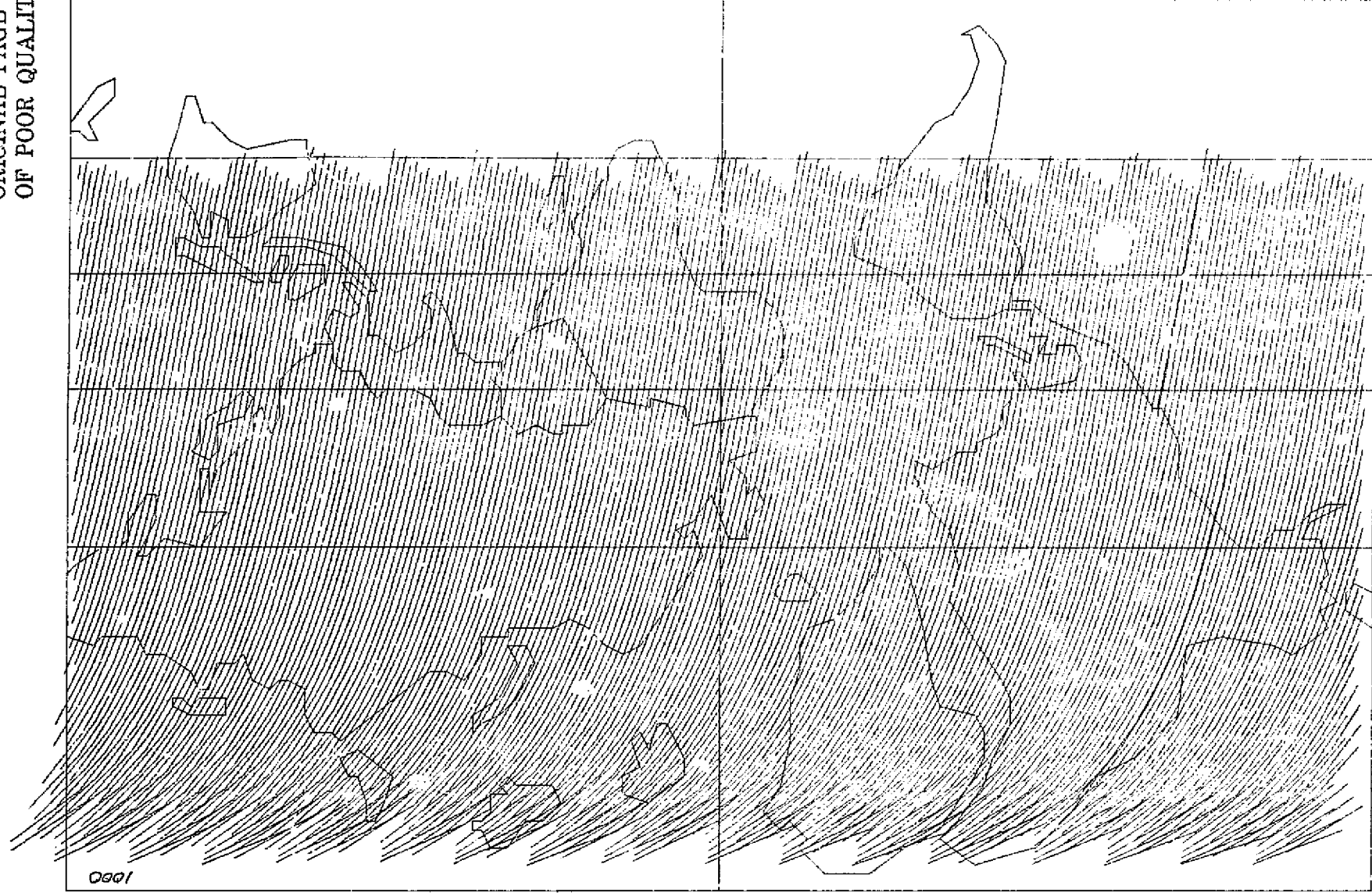
FIGURE PACK 13 - LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

Data:

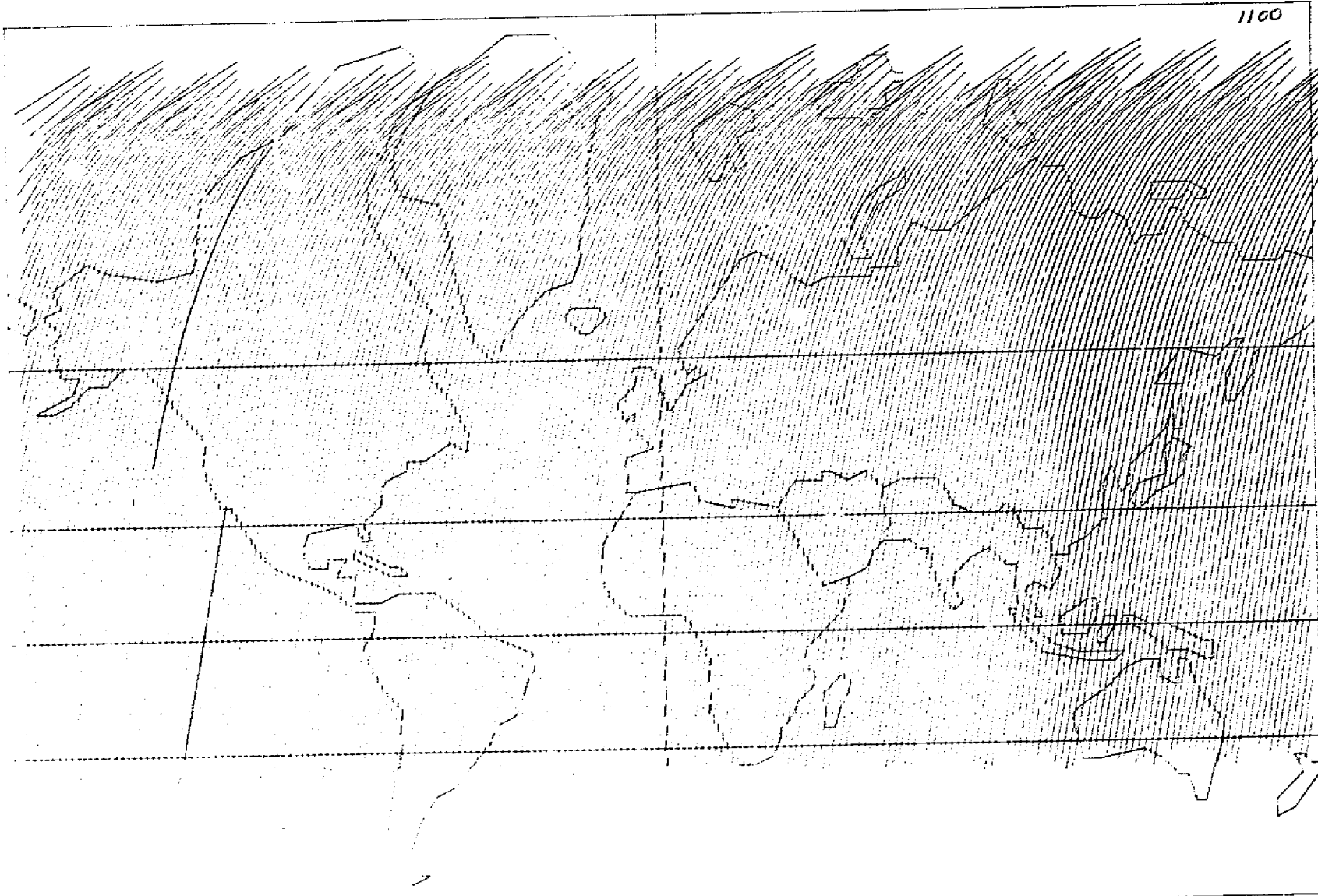
Launch site	VAFB
Inclination	96.6 degrees
Altitude	273.7 kilometers
Launch date	1 July
Launch time	0900 to 1500 hours (hourly)



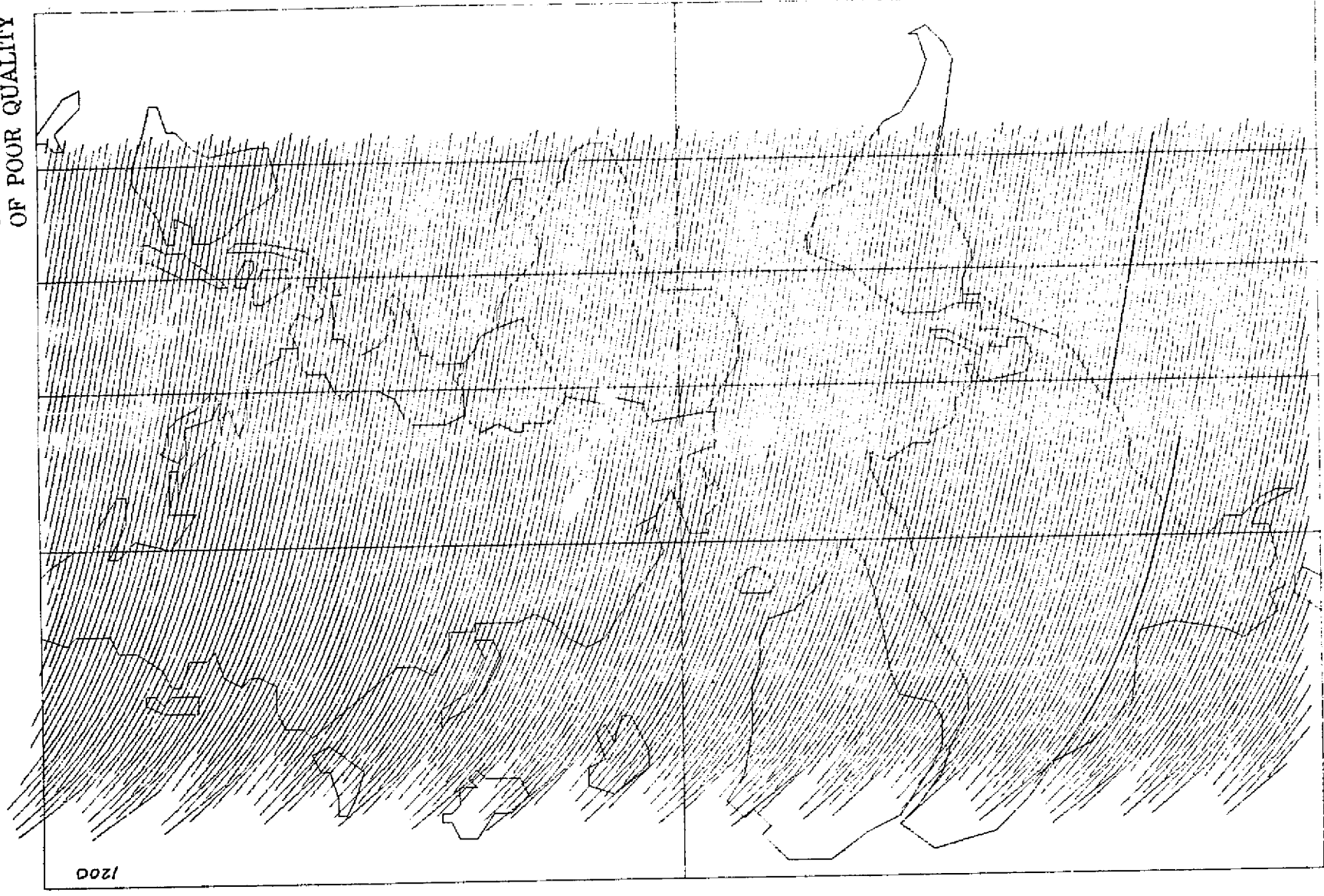
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B-101

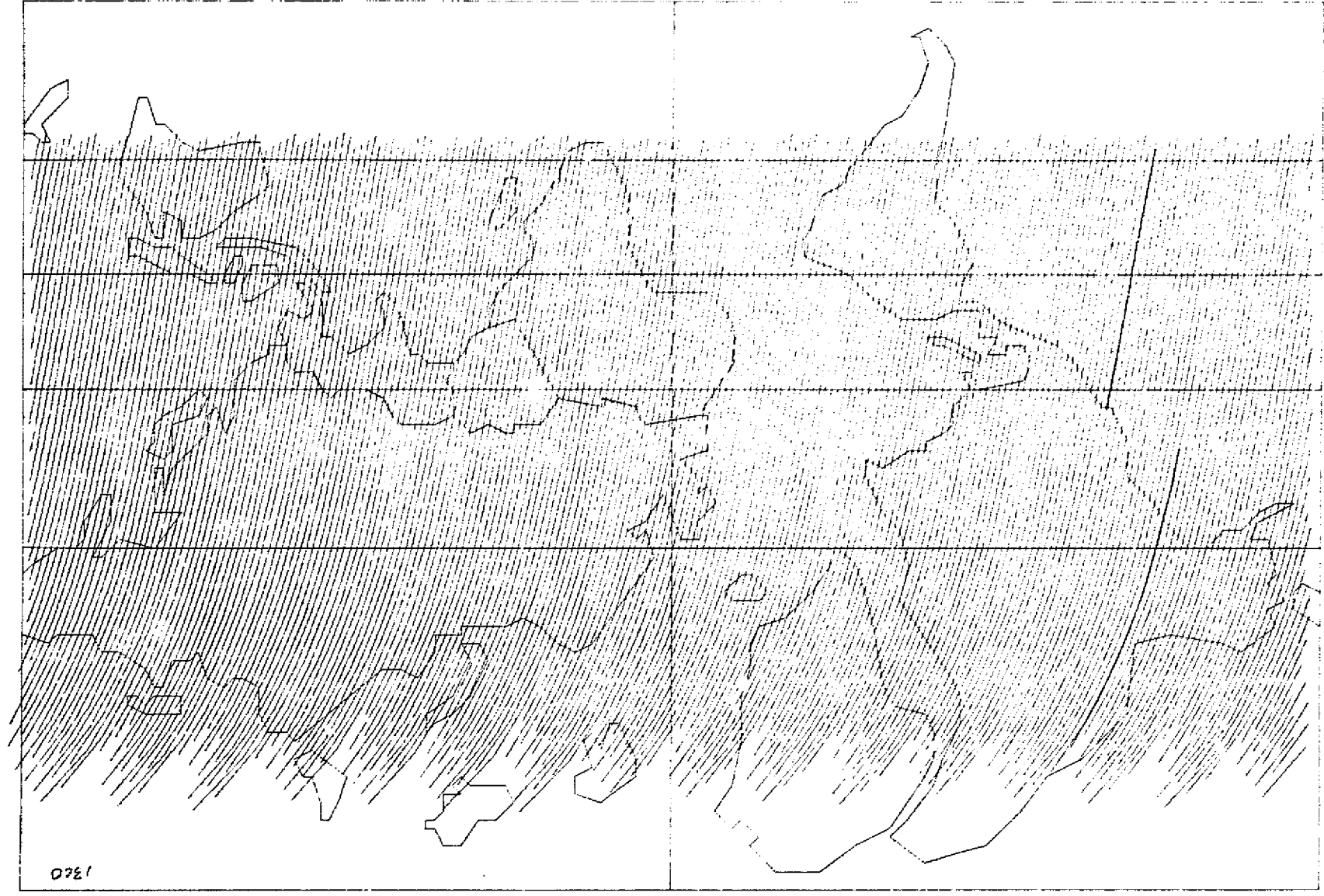


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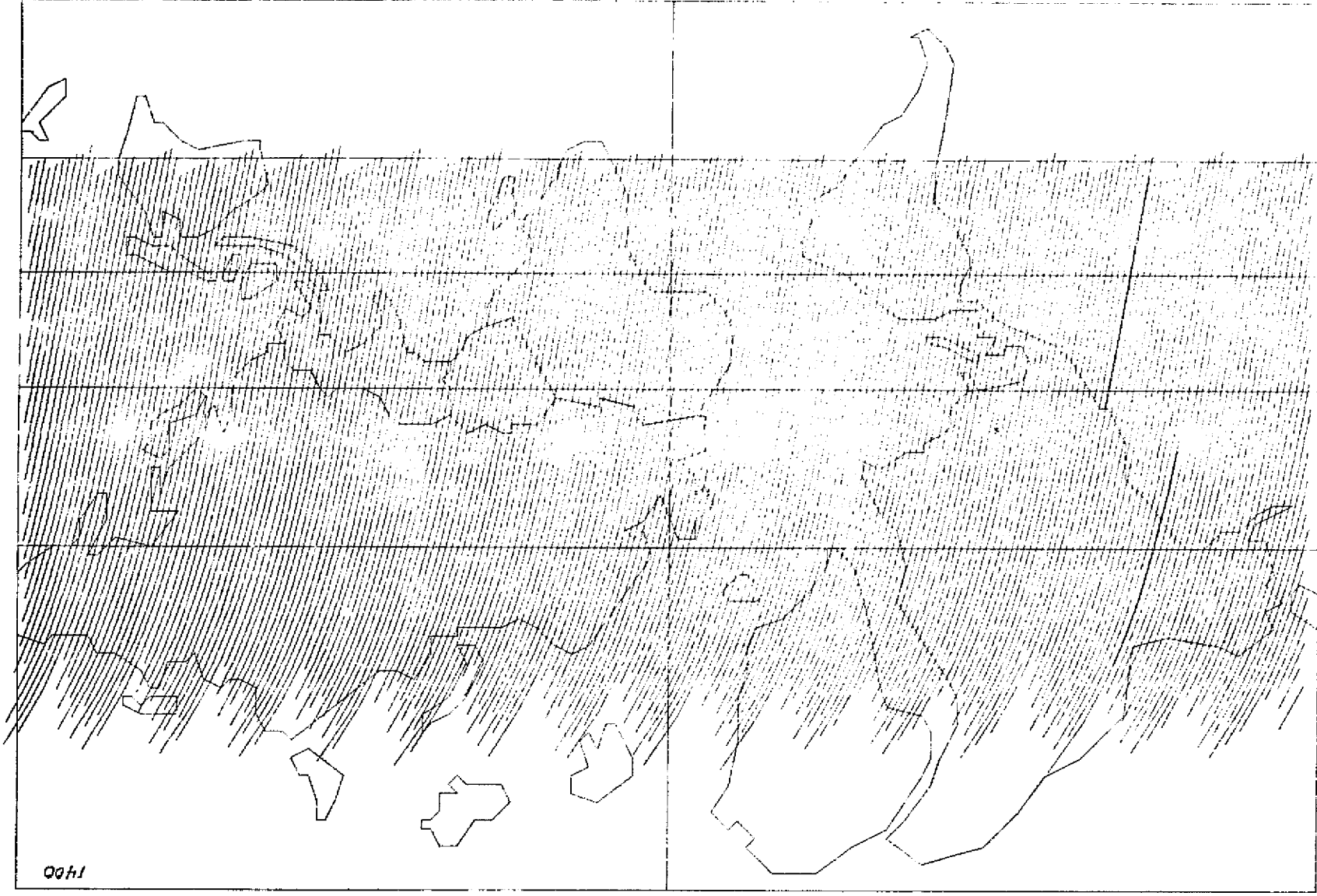


1200

B-103



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B-105

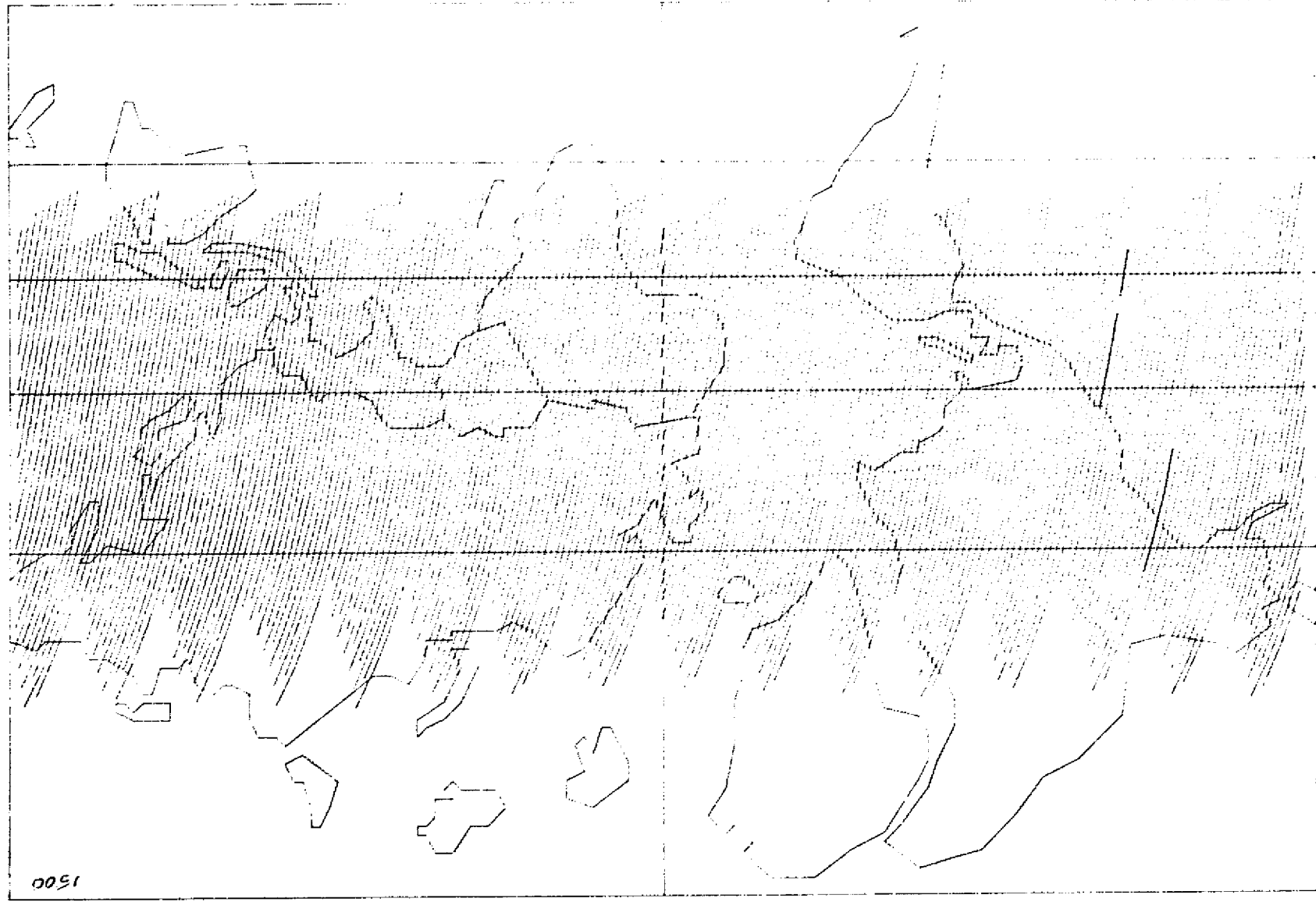
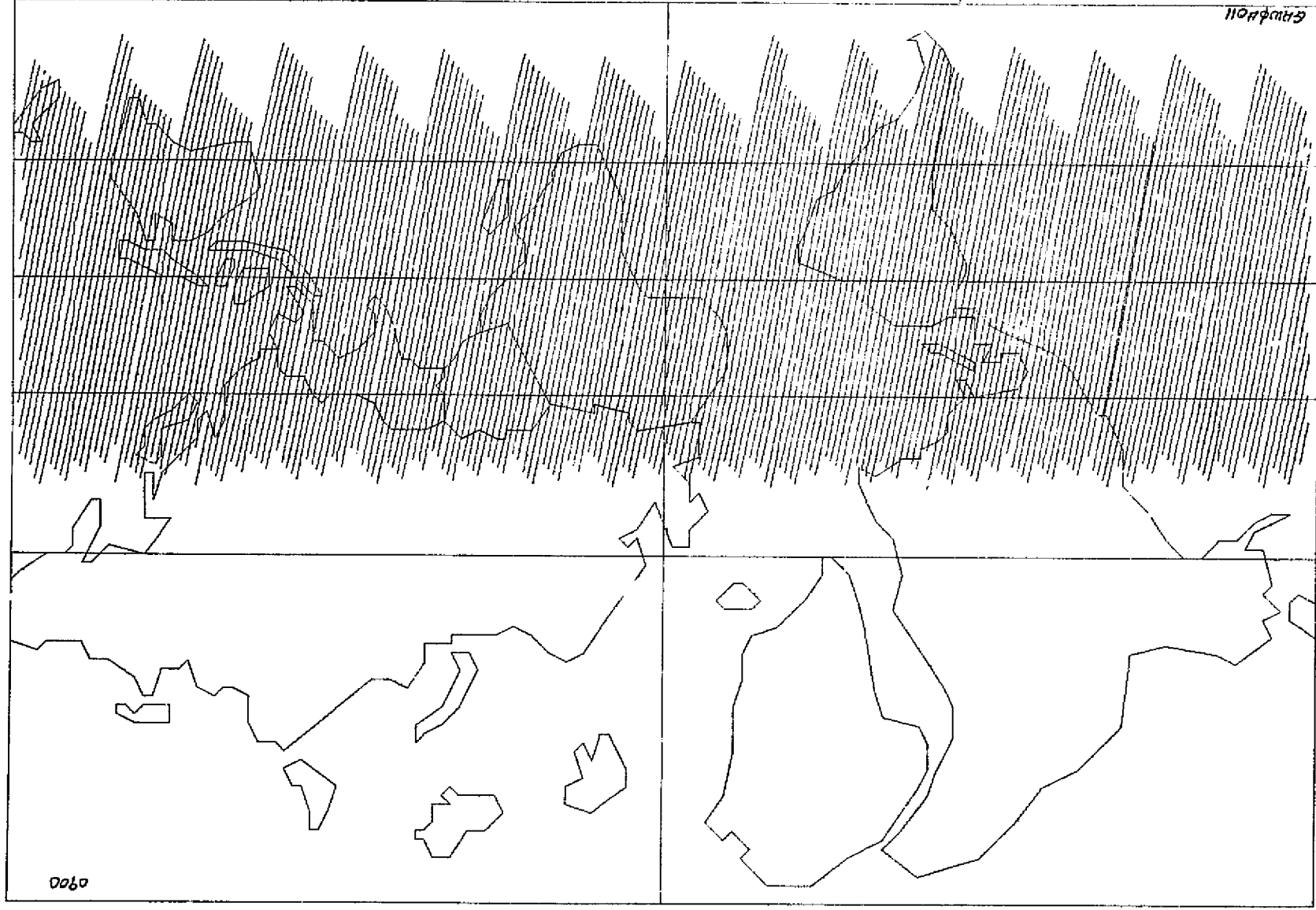


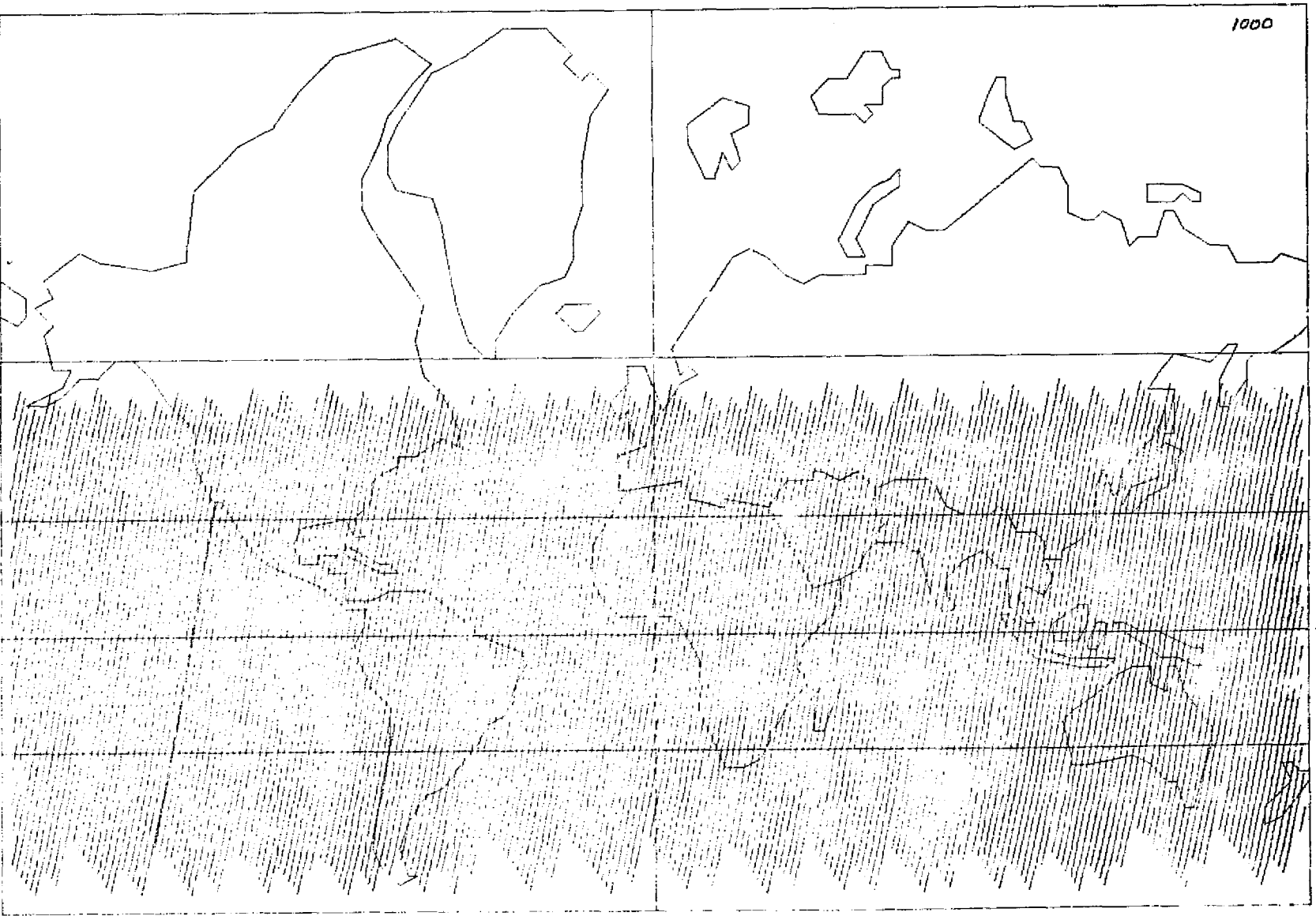
FIGURE PACK 14 — LAUNCH DAY AND TIME
VERSUS ILLUMINATION CONDITIONS

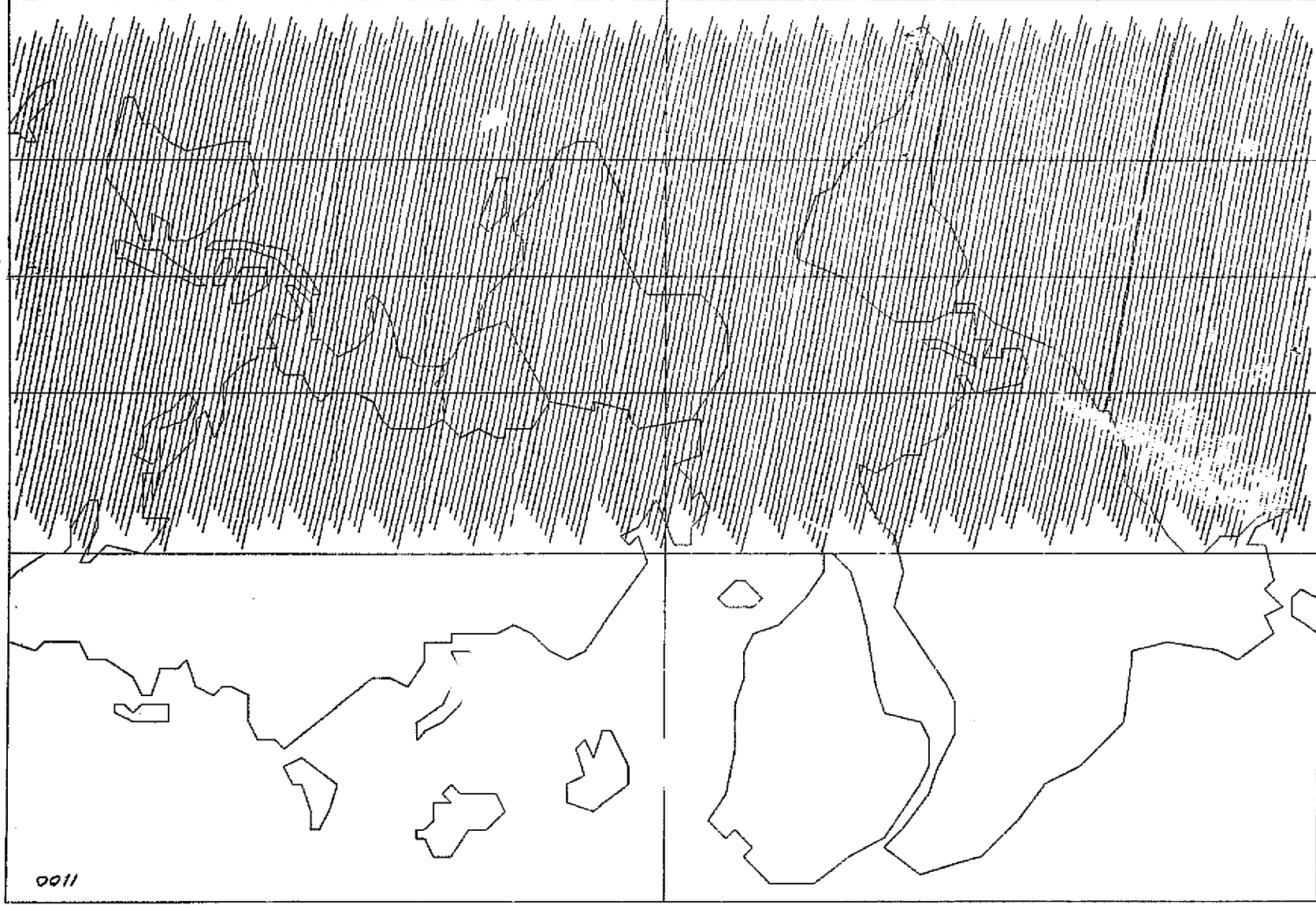
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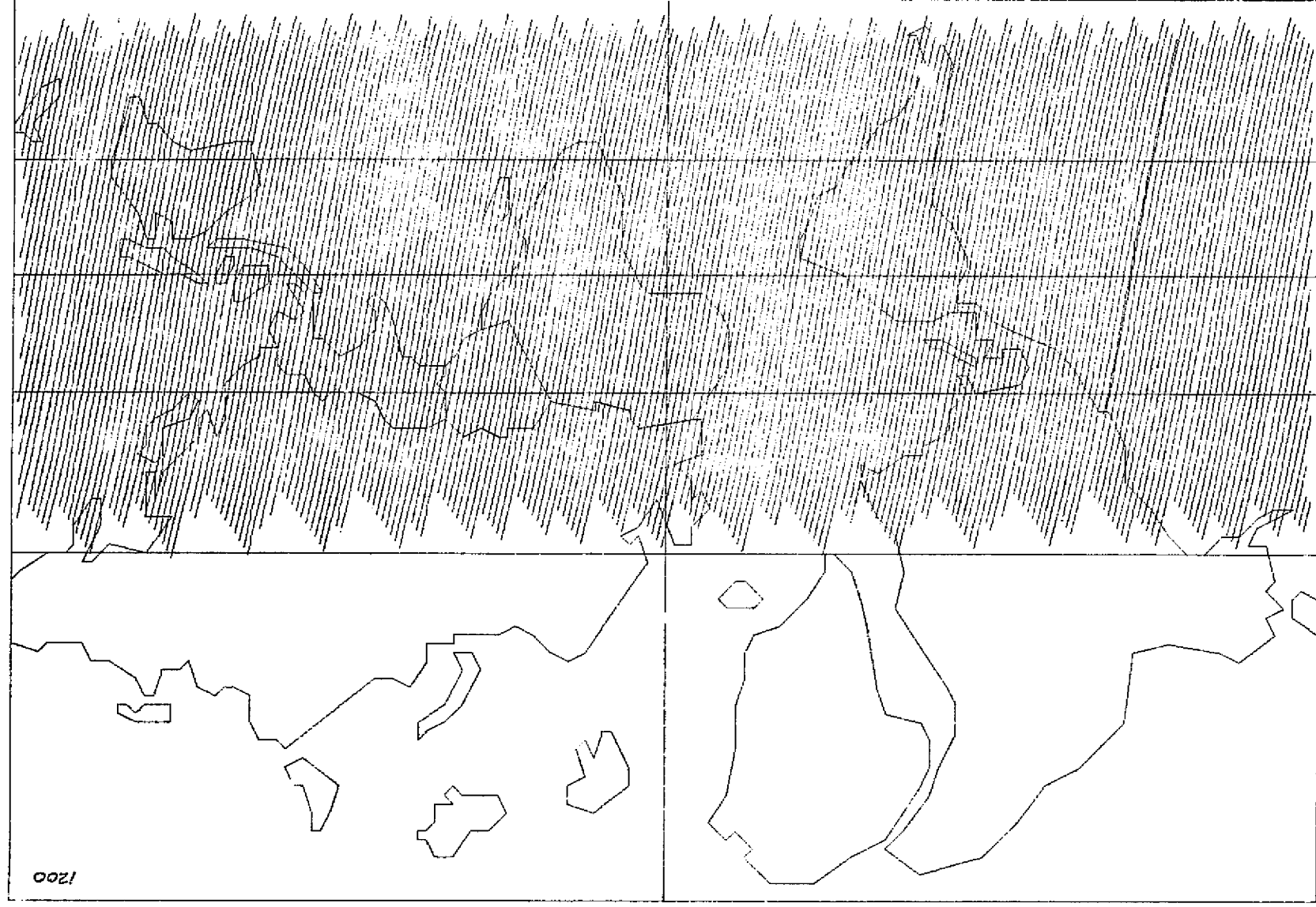
Launch site	VAFB
Inclination	96.6 degrees
Altitude	273.7 kilometers
Launch date	1 October
Launch time	0900 to 1500 hours (hourly)



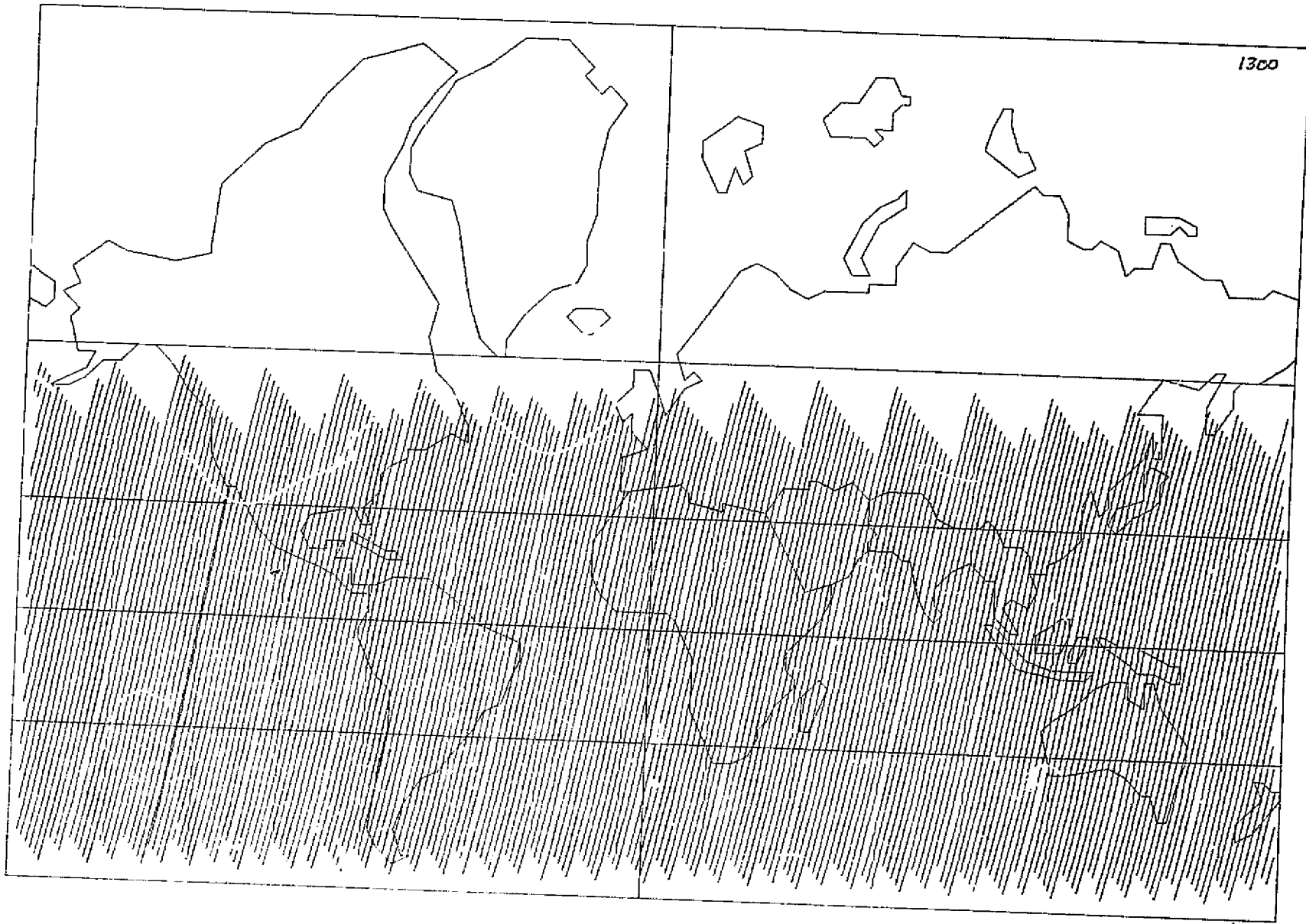
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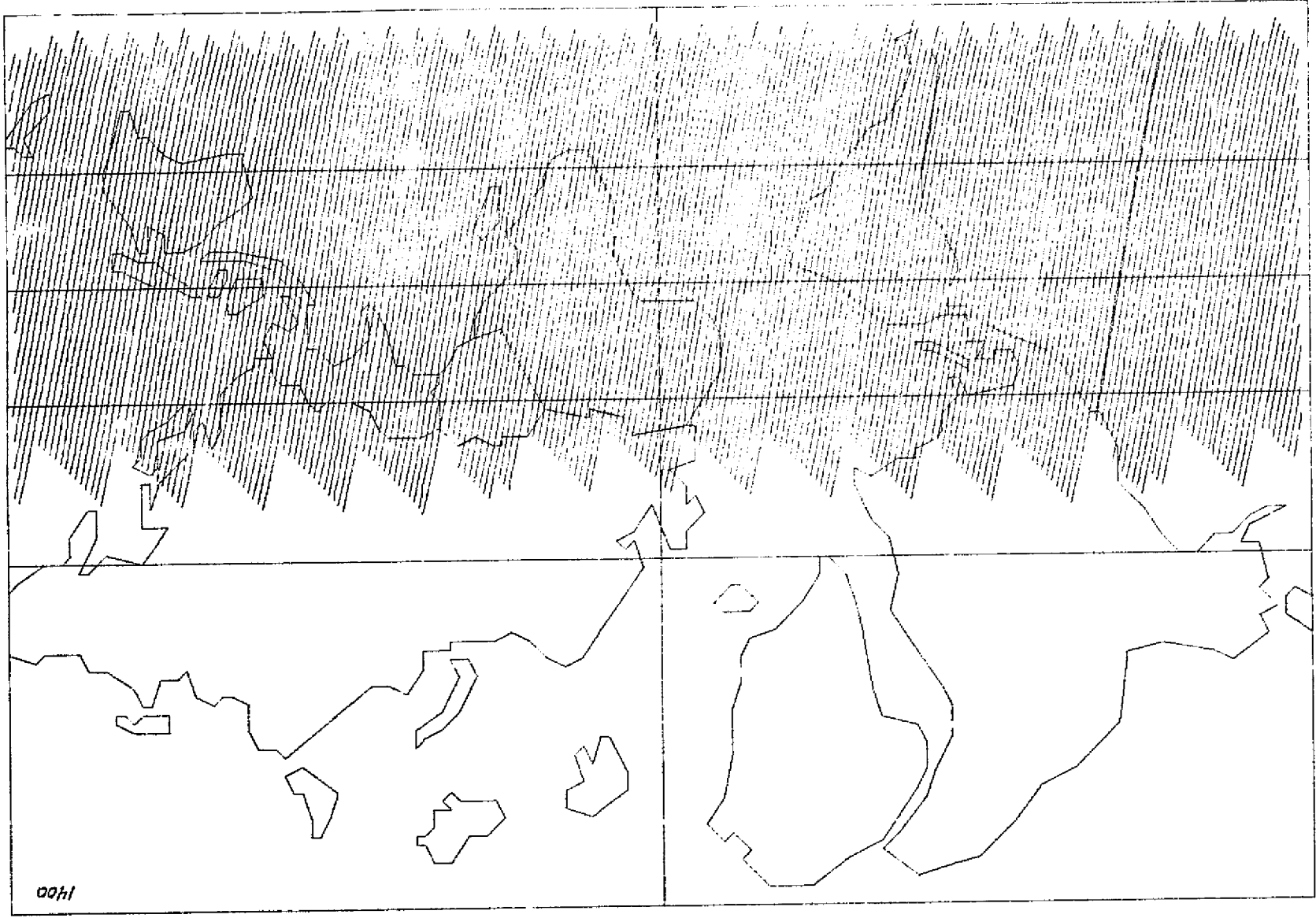


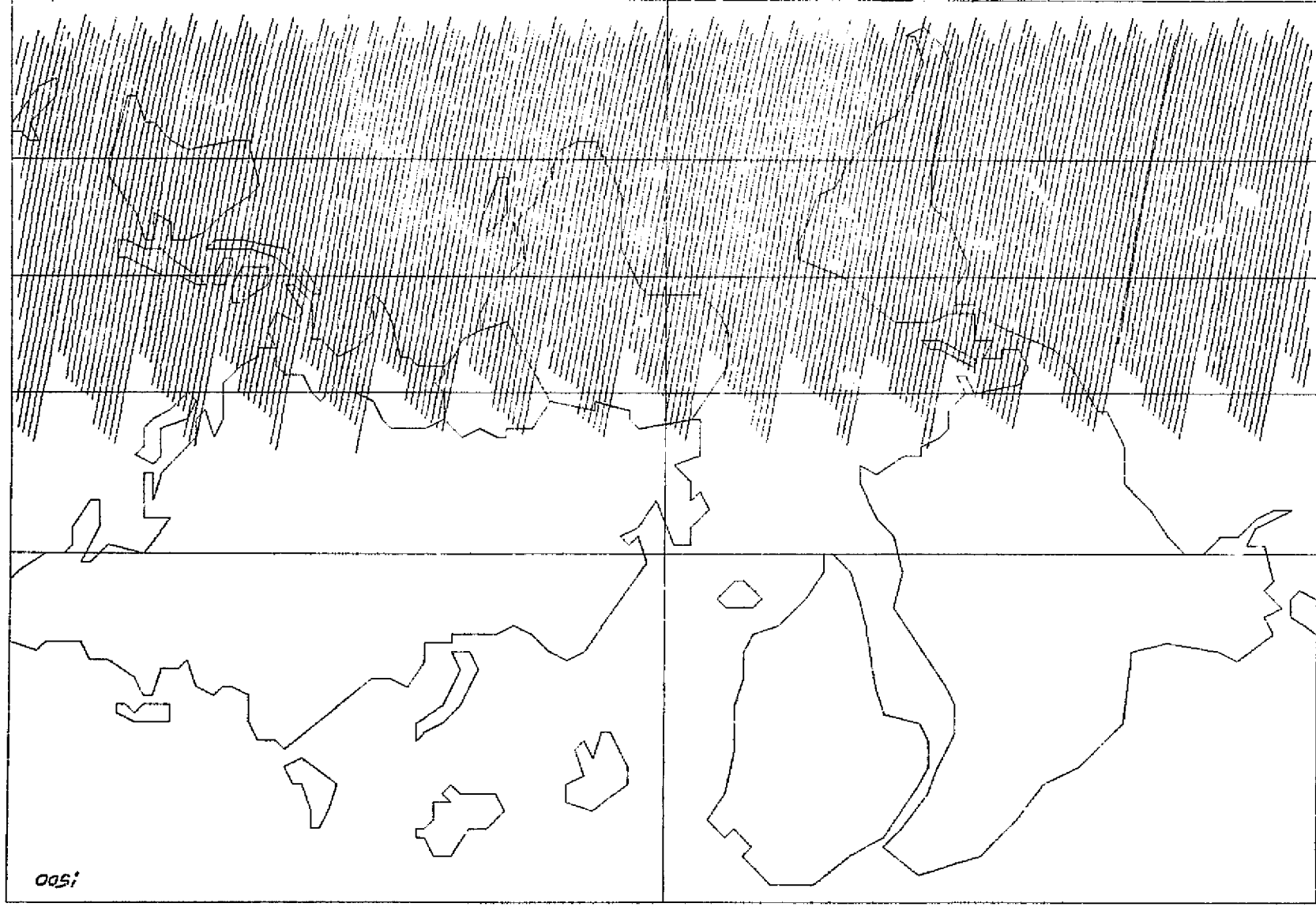
1300



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1500

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DATE
FILM
ALBION